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POISONING OF RAPTORS WITH ORGANOPHOSPHORUS AND CARBAMATE PESTICIDES WITH EMPHASIS ON CANADA, U.S. AND U.K.

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ABSTRACT.—We reviewed cases of raptor mortality resulting from cholinesterase-inhibiting pesticides. We compiled records from the U.S., U.K. and Canada for the period 1985–95 (520 incidents) and surveyed the relevant literature to identify the main routes of exposure and those products that led to the greatest number of poisoning cases. A high proportion of cases in the U.K. resulted from abusive uses of pesticides (willful poisoning). The proportion was smaller in North America where problems with labeled uses of pesticides were as frequent as abuse cases. Poisoning resulting from labeled use was possible with a large number of granular pesticides and some seed treatments through secondary poisoning or through the ingestion of contaminated invertebrates, notably earthworms. With the more toxic products, residue levels in freshly-sprayed insects were high enough to cause mortality. The use of organophosphorus products as avicides and for the topical treatment of livestock appeared to be common routes of intoxication. The use of insecticides in dormant oils also gave rise to exposure that can be lethal or which can debilitate birds and increase their vulnerability. A few pesticides of high toxicity were responsible for the bulk of poisoning cases. Based on limited information, raptors appeared to be more sensitive than other bird species to organophosphorus and carbamate pesticides. Some of the more significant risk factors that resulted in raptor poisonings were: insectivory and vermivory; opportunistic taking of debilitated prey; scavenging, especially if the gastrointestinal tracts are consumed; presence in agricultural areas; perceived status as pest species; and flocking or other gregarious behavior at some part of their life cycle. Lethal or sublethal poisoning should always be considered in the diagnosis of dead or debilitated raptors even when another diagnosis (e.g., electrocution, car or building strike) is apparent. Many cases of poisoning are not currently diagnosed as such and, even when diagnosed, the information is often not made available to regulatory authorities. The importance of pesticide intoxications relative to other sources of mortality is highly variable in time and place; on a regional level, the increased mortality of raptors resulting from cholinesterase-inhibiting pesticides can be significant, especially in the case of rare species.

KEY WORDS: *pesticides; anticholinesterases; poisoning; raptors; agriculture.*

Intoxicación de los Rapaces con Pesticidas Organofosfórico y Carbamate con Énfasi en Canadá, Estados Unidos y el Reino Unido

RESUMEN.—Examinamos los casos de mortalidad de los rapaces debido a los pesticidas colinasterase-inhibidores [cholinesterase-inhibiting]. Recopilamos documentos de los Estados Unidos, el Reino Unido y Canadá por el período de 1985–95 (520 incidentes) y estudiamos la literatura referente a esto para identificar las rutas principales de la extensión del riesgo al cual se exponen y examinar los productos que llevan a un gran número de casos de intoxicación. Un gran porcentaje de casos en el Reino Unido es el resultado del abuso en el uso de pesticidas (envenenamiento deliberado). La proporción es más pequeña en América del Norte donde los problemas con usos descritos de pesticidas es tan frecuente como los casos de abuso. La intoxicación que resulta del uso descrito es posible con un gran número de pesticidas granulares y algunos tratamientos de semilla mediante envenenamiento secundario o por medio de la ingestión de invertebrados contaminados, en forma notable las lombrices. Con los productos más tóxicos, el nivel de residuo en los insectos recién rociados es suficientemente alto para causar la mortalidad. El uso de los productos organofosfatos como avicidas y para el tratamiento corriente del ganado parece ser la ruta común de intoxicación. El uso de insecticidas en el aceite mineral insecticida, también aumenta la extensión de riesgo al que están expuestos que puede ser mortal o que puede debilitar a los pájaros e incrementar su vulnerabilidad. Algunos pesticidas del alta toxicidad son responsables por el volumen de casos de envenenamiento. En base a la información limitada, parece ser que los rapaces son más sensibles que otras especies de aves a los pesticidas organofosfóricos y carbamate [carbamate]. Algunos de los factores de riesgo más significativos que causa la intoxicación en los rapaces son el hecho de ser insectívoros y vermívoros; la toma oportunista de la presa debilitada; la alimentación de carroña, especialmente si la región gastrointestinal está consumida; la presencia en áreas agrícolas; la condición percibida como especies de plaga; y la congregación en bandada u otra conducta gregaria en alguna parte de su ciclo de vida. La intoxicación mortal o submortal debe considerarse siempre en el diagnóstico de los rapaces muertos o debilitados, aún cuando se manifieste otro diagnóstico (ej. electrocución, golpearse o estrellarse contra un carro o edificio). Muchos casos de envenenamiento actualmente no se diagnostican como tales y, aún cuando son diagnosticados, a menudo la información no está disponible a las autoridades reguladoras. La importancia de las intoxicaciones de pesticidas relativa a otras fuentes de mortalidad es altamente variable en tiempo y lugar; a nivel regional, la mortalidad aumentada de rapaces causada por los pesticidas colinaestarase-inhibidores puede ser significativa, especialmente en el caso de las especies poco comunes.

[Traducción de Anne Grondin y Marguerita Merino]

The link between declines of some raptor populations and organochlorine insecticide (OC) contamination has been well established. OC contamination is still of concern in many parts of the world because of their continuing use and heavy contamination from prior use. In most developed countries, the more acutely toxic and/or bioaccumulating OCs were replaced by the shorter-lived but acutely toxic cholinesterase (ChE)-inhibiting organophosphorus (OP) and carbamate (CB) pesticides. Despite advances in pest control and the introduction of more targeted products, ChE inhibitors are still ubiquitous. Because of their acute toxicity, OP and CB compounds are frequently implicated in abuse cases where raptors or other vertebrates are targeted directly; however, there is an increasing number of reports of poisonings caused by labeled uses of these products. Some kills can be very large, such as the recent loss of several thousand Swainson's Hawks (*Buteo swainsoni*) (see Appendix 1 for Latin names; nomenclature follows del Hoyo et al. [1994]) in Argentina (Woodbridge et al. 1995, Goldstein et al. 1996, Goldstein 1997, Canavelli and Zaccagnini 1996). Based on a review of both published and unpublished cases, we evaluated those factors responsible for the kills, namely the toxicity of registered products and the extent to which their formulation enhanced exposure, as well as the dietary and social habits of raptors and their use of agricultural habitats for foraging. While we emphasized incidents reported from Canada, U.S. and U.K. during 1985–95, our intent was to provide a comprehensive review of known poisoning cases. Our objective was to go beyond descriptions of mortality to establish a commonality among incidents and to identify the main factors responsible with a view toward mitigation.

WHY RAPTORS?

Many bird species are known to be killed routinely by ChE-inhibiting pesticides. In what was the first review of such poisonings in North America, Grue et al. (1983) listed 52 species from 15 bird families being killed in 30 documented incidents between 1965–83. A review of wildlife incidents occurring in England and Wales between 1964–83 also reported several cases of poisoning with anticholinesterase pesticides in a broad range of species (Hardy et al. 1986). Our review is restricted to raptorial species as well as to both Old and New World vultures (e.g., Accipitridae, Falconidae, Cathartidae and Strigidae). From an ecological perspective, these birds are generally long-lived and have deferred maturity. From a pragmatic point of view, several raptor species may be useful as sentinels in agricultural habitats. For example, scavenging species such as the Bald Eagle (*Haliaeetus leucocephalus*) are much more likely to detect primary pesticide kills than human observers (Elliott et al. 1996, Elliott et al. 1997).

METHODS

The main sources of information for this review were incidents involving raptors reported to authorities in Canada, U.S. and U.K. Complete lists of cases occurring between 1985–95 were obtained from the Canadian Wildlife Service and Canadian Cooperative Wildlife Health Centers (CCWHC), and from the records held by the Central Science Laboratory for the U.K. Cases from 1985–94 in the U.S. were compiled from records held by the U.S. Fish and Wildlife Service (USFWS), Environmental Protection Agency (USEPA) and Biological Resources Division of the U.S. Geological Survey (USGS) at the National Wildlife Health Center. Some of the North American incidents were already tallied by state (Thomas and Franson 1993, Glaser 1994, Franson et al. 1995) but, with few exceptions (e.g., some owls [Blus 1996]), they have not been otherwise published or analyzed. All of the U.K. incidents have been published on a yearly basis (Fletcher and Hardy 1986, Fletcher et al. 1989, Fletcher et al. 1990, Fletcher et al. 1991, Fletcher and Hunter 1993, Fletcher et al. 1994, Fletcher et al. 1995, Fletcher et al. 1996, Fletcher et al. 1997). Some of the Canadian incidents have already been described (Elliott et al. 1996, Elliott et al. 1997) or summarized in newsletters of the CCWHC. Others have been tabulated (Wilson et al. 1995) but not otherwise described.

We ascribed a 'certainty index' to each incident denoting the amount of information available. We recognized the following categories: (1) identified chemical residues in tissues, gut contents or bait material and ChE evidence; (2) identified chemical residues and circumstances clearly indicative of poisoning (e.g., cases of mass mortality, signs, likely route of exposure and source of pesticide identified); (3) ChE evidence and circumstances clearly indicative of poisoning but chemical residues nondetectable or not analyzed; (4) ChE evidence only with no ancillary information, residues nondetectable or not analyzed (in this category, the nature of the ChE evidence was key to the significance attached to the incident; ChE evidence can be at levels very much below normal, reactivation data or serially obtained measurements for live birds only showing recovery with time); (5) circumstances clearly indicative of poisoning such as reports of mass mortality following specific pesticide use but no chemical or biochemical data available; often clinical signs are consistent with poisoning and other likely causes of death (e.g., pathogens, electrocution and shooting) have been eliminated; here, negative chemical analysis and/or ChE data would likely make us discard the incident.

We used details supplied with the incident record such as any forensic data (e.g., the nature of gut contents) to ascribe a probable cause. For example, we categorized any Canadian or U.S. incident report mentioning that coyotes (*Canis latrans*), wolves (*Canis lupus*) or large numbers of raccoons (*Procyon lotor*) were also found dead along with the raptors as an abuse case. For this review, we used best scientific judgment to categorize incidents We recognize that, in several cases, the information available might be judged inadequate by legal standards. We also had to exercise scientific judgment in deciding what constituted a single incident. Coincidence of time and place and the identity of the residues obviously weighed strongly in this decision. With few exceptions (Stinson et al. 1994) the incidents did not result from specific research or monitoring exercises associated with a specific pesticide treatment. Kills recorded in the course of industry-sponsored field studies (e.g., Booth et al. 1986) were not included in the tallies, but are reviewed in the discussion where appropriate. We did this to avoid introducing another bias in the record given that not all pesticides have had the same degree of scrutiny. We extended the time period backwards or forward to capture other incidents when these offered useful insights. The dates 1985–95 corresponded with a general increase (in North America at least) in the effort made to document raptor mortality following poisoning with anticholinesterase compounds. We were able to find only 11 records of raptors being poisoned by ChE-inhibiting pesticides before that period. Mendelssohn and Paz (1977) reported that ChE poisonings were not well documented but, after their work on the OP famphur, Henny et al. (1985) suggested that the lack of OP secondary poisoning reports for birds of prey in North America might be due to the limited number of dead raptors being analyzed for ChE depression and OP residues. At about that time, the USEPA was engaging in reviews of the insecticides diazinon and carbofuran because of documented wildlife mortality. This resulted in a general increase in the reporting of wildlife kills.

In the U.K., a wildlife incident scheme with more constant reporting effort has been in operation for more than 30 yr (Hardy et al. 1986, Greig-Smith 1991). The choice of the period 1985–95 was purely arbitrary.

BIASES INHERENT IN A PASSIVE INCIDENT SCHEME

Most of the information reported here originated from reported cases of mortality and, as such, was subject to many biases and limitations. First of all, it was very difficult to assess what proportion of incidents were reported to national authorities and were therefore available for tabulation and analysis. For example, on the basis of personal communications from local authorities and rehabilitation centers, Fry et al. (1998) accounted for 34 Red-tailed Hawks (*Buteo jamaicensis*) poisoned by OP insecticides mixed in dormant oil sprays in California almond orchards between 1987–90; 18 hawks died and 16 were treated with atropine and released. Hooper et al. (1989) working on a subset of those birds described two parathion-poisoned hawks as well as four more hawks brought to rehabilitation centers with depressed plasma ChE, symptoms of poisoning and mixed OP residues on their feet. Furthermore, eight of 12 wild-caught birds in orchards exhibited reduced ChE levels although only one showed signs of poisoning. Only the two parathion-poisoned birds ($<6\%$ of known cases) appeared in the combined data bases of the USEPA and USGS for the same time period. Contacting every competent state and local authority was beyond the scope of this review. Therefore, we used only a limited subset of documented incidents, at least in the U.S. We did not know whether these cases were a representative subset. Since then, the USEPA increased its efforts to collect incident information from competent authorities (Anonymous 1994). The proportion of documented incidents over all incidents was even more difficult to estimate.

Secondly, the information available on each incident was of uneven quality and there were often many unknowns. Numbers of birds reported should be treated as minima. For example, in a few cases, the plural form (e.g., eagles) was the only indication as to the number of birds involved. Two individuals were ascribed to such incidents and "several birds" was taken to mean at least three.

There were systematic biases associated with incident reporting. In the U.S., cases involving Bald and Golden Eagles (*Aquila chrysaetos*) were more likely to be investigated fully because these species have federal protection. Also, because of regulatory initiatives such as Special Reviews (re-evaluations of specific pesticides and specific use patterns in response to a perceived problem) initiated by the USEPA, there has been a more intensive focus on some products; for example, the insecticides diazinon and carbofuran. Large-bodied birds or flocking birds have a higher probability of being discovered (Baillie 1993). Because of delays in reporting, as well as frequent omission of critical data, causality for many raptor incidents can be difficult to establish. Having access to all the information surrounding any given incident is particularly relevant in trying to distinguish malicious poisoning of birds and other gross pesticide label violations from incidents resulting from normal agricultural practice. The distinction is important because the solutions are different. In the first case, education and legal enforcement of existing statutes can solve abuses of pesticides and, in the second case, changes in agronomic uses and regulatory changes to registered pesticide use patterns are needed to solve problems arising from labeled uses. Pesticide misuse is also a recognized problem although the term has been used so loosely that its significance is often unclear. Also, the word misuse has been used in North America to mean malicious intent in much the same context as abuse in European terminology (Fletcher et al. 1996). The simplest definition of misuse is unintentional failure to follow label instructions. However, a misuse in one jurisdiction may indeed be a registered use in the next. Also, a certain degree of flexibility in label interpretation is allowed under most national pesticide legislation. In the case of Swainson's Hawk mortality in Argentina, the insecticide monocrotophos, although not specifically labeled for grasshopper control, was officially tolerated and even promoted for that use because no generally-recognized interdiction existed and because the pesticide was registered for other pest species at the same rates and on the same crops (Mineau 1996). In some cases, misuse was reported because rates applied were too high or the products applied poorly (e.g., some granular insecticides present on the soil surface rather than buried). However, it has been repeatedly demonstrated that the ability of farmers and pesticide applicators to follow labels exactly is highly variable under real-life conditions (Rider and Dickey 1982, Ellis 1982, Thompson et al. 1985). Even under carefully calibrated and monitored conditions, pesticide applications are highly variable (Maze et al. 1991). Finally, it has been argued (Mineau 1993) that some labels are simply untenable. For example, any application of carbofuran in Canada should be considered a misuse because the label clearly states that it should be kept out of areas inhabited by fish, birds and wildlife because it is highly toxic to such animals. Implicit in this label statement is the (mistaken) assumption that birds and other wildlife species do not frequent agricultural fields. In this review, we did not describe any incidents as cases of misuse. Instead, based upon the apparent severity of the infraction, we ascribed them either to abuse or to labeled use. Cases where interpretation was difficult were discussed in the text or alternatively, we simply left them as "use unknown."

For several reasons, cases of pesticide abuse are more likely to be reported than other cases or, at least, to be recognized as such. These cases frequently result from the use of highly concentrated baits, and birds often do not go far from the site of intoxication (Greig-Smith 1987a). Birds which fly away from the site of exposure are unlikely to be analyzed for exposure to ChE-inhibiting pesticides. For example, in response to a request for carcasses, the Institute of Terrestrial Ecology in Britain received 276 Eurasian Sparrowhawks (*Accipiter nisus*) and 56 Common Kestrels (*Falco tinnunculus*) between 1987–90 (Newton et al. 1992). Those carcasses were analyzed for OC residues, but not for ChE-inhibiting pesticides. During that same period, the pesticide incident scheme reported that one sparrowhawk (out of 22 received) and one kestrel (out of 28 received) had tested positive for ChE inhibitors. The pesticide incident scheme in the U.K. collects birds primarily associated with agricultural operations. Therefore, even where there were good working schemes for investigating field kills, it was unlikely that individuals that were found on roads or near habitations were tested routinely for currently used pesticides. In the lower Fraser estuary of British Columbia, Canada, most reported raptor mortality was from overnight roost sites in urban and suburban parks. Given the nature of residues detected, it appeared the birds were poisoned in the course of their day-time foraging trips into agricultural fields, but most were able to fly to their night roosts before succumbing. It was not until a systematic effort to recover and analyze carcasses and moribund individuals from rehabilitation centers began in 1990 that the incidents were documented as pesticide-related.

Also, the investigation of abuse is often pursued more vigorously and carefully because of legal imperatives; unfortunately, information pertaining to these incidents may be withheld for legal reasons resulting in fragmentary data being made available for a period of a few years after the incident. Another factor which favored the reporting of abuse cases over labeled ones was that abuses are considered less sensitive in that they do not reflect poorly on a jurisdiction's agricultural operations or pesticide regulatory system. Also, pesticide users may be reluctant to report problems stemming from labeled uses if they believe the pesticide implicated is essential to their livelihood.

RESULTS AND DISCUSSION

A total of 255, 102 and 63 incidents were reported for raptors over the period 1985–95 (Table 1). Of these, most were either given certainty indices of 1 or 2 (Fig. 1). Incidents were further tallied either by the chemical and type of incident involved (Tables 2, 3, 4) or by the species killed (Tables 5, 6, 7).

Abuse vs. Labeled Use of Pesticides. The extent to which incidents result from pesticide abuse as opposed to approved uses is usually the first question asked by any pesticide incident reporting system. In the U.K., the criminal abuse of pesticides for killing birds of prey has long been acknowl-

Table 1. Yearly tally of U.S., U.K. and Canadian raptor mortality incidents involving pesticides from 1985–95.

	U.S.		U.K.		CANADA	
YEAR	NO. INCIDENTS	MINIMUM NO. BIRDS	NO. INCIDENTS	MINIMUM NO. BIRDS	NO. INCIDENTS	MINIMUM NO. BIRDS
1985	13	20	10	13	—	—
1986	21	32	16	19	—	—
1987	23	47	3	3	—	—
1988	33	74	4	5	—	—
1989	26	93	16	23	—	—
1990	23	46	1	1	9	13
1991	29	168	6	11	2	2
1992	33	85	8	10	11	27
1993	24	88	11	15	8	37
1994	31	82	13	14	17	18
1995	N/A	N/A	14	21	16	25
Total	255	734	102	136	63	122

edged and is of conservation concern (Brown et al. 1977, Cadbury 1980, Elliott and Avery 1991). In addition to birds of prey, corvids and several wild and domestic mammal species are also targeted by applications and raptors killed inadvertently. These kills are usually related to gamebird rearing, lamb production and attempts to protect racing pigeons. In the U.K., yearly proportions of incidents ascribed to deliberate abuse of pesticides relative to the total number of incidents reported involving agricultural pesticides with all bird and mammal species ranged from 65–82% (median = 71%) of 64–127 incidents per year (Greig-Smith 1988). The proportion of abuses against raptors over the 1985–94 period was 87% (Table 3). There was probably a slight overrepresentation of abuse cases because only incidents with certainty indices of 1 and 2 were tabulated. Often, the diagnosis of abuse was made on the basis that there was no longer an approved registration for the given pesticide and it did not always result from an intent to kill raptors or other vertebrates. For example, fenthion does not have an approved use as a treatment for ectoparasites in sheep although it was approved for the

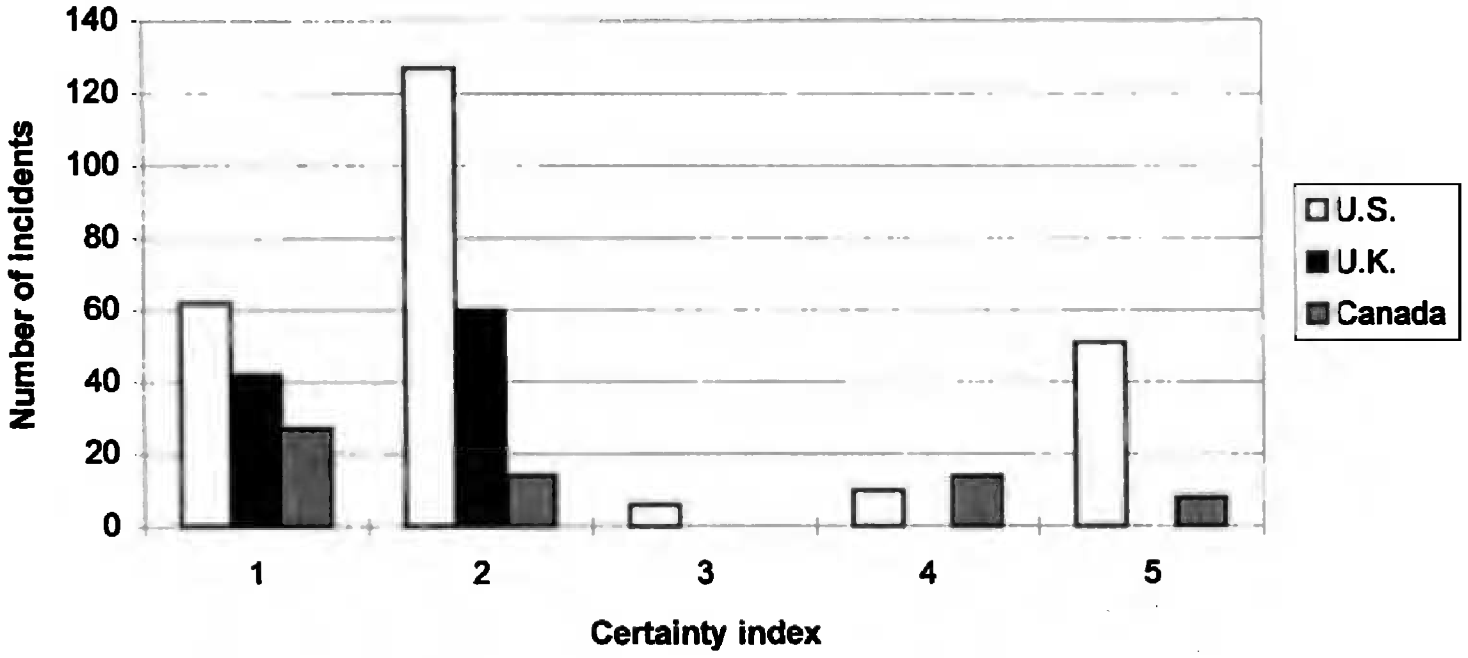

Figure 1. Certainty index for incidents tabulated in this review. 1—identified residues in tissues, gut contents or bait material and ChE evidence. 2—identified residues and circumstances clearly indicative of poisoning. 3—ChE evidence and circumstances clearly indicative of poisoning. 4—ChE evidence. 5—circumstances clearly indicative of poisoning.

Table 2. Summary of pesticides implicated in U.S. raptor kills (1985–94) according to whether they were thought to have resulted from labeled use, abuse, spill or where the use pattern was unknown.

	No. Incidents					
	Labeled Use	Abuse	Spill	Unknown Use	Total	Minimum No. Birds
Pesticide						
aldicarb	—	4	—	3	7	12
carbofuran	25	55	—	36	116	406
chlorpyrifos	3	—	1	—	4	4
coumaphos	—	—	—	1	1	1
diazinon	—	—	—	2	2	2
dicrotophos	—	—	—	1	1	2
disulfoton	1	—	—	—	1	21
famphur	6	8	—	37	51	68
fenthion	18	1	—	10	30	72
parathion	2	—	—	5	7	26
phorate	2	2	1	2	7	15
phosphamidon	—	1	—	—	1	3
terbufos	—	—	—	3	3	12
unknown	—	—	—	17	17	22
Mixtures						
carbofuran and methomyl	—	1	—	—	1	3
chlorpyrifos and diazinon	4	—	—	—	4	4
chlorpyrifos and fonofos	—	1	—	—	1	59
chlorpyrifos, diazinon and methidathion	2	—	—	—	2	2
Totals	63	73	2	117	255	734

Table 3. Summary of pesticides implicated in U.K. raptor kills (1985–95) according to whether they were thought to have resulted from labeled use, abuse, spill or where the use pattern was unknown.

	No. Incidents					
	Labeled Use	Abuse	Spill	Unknown Use	Total	Minimum No. Birds
Pesticide						
aldicarb	—	—	—	1	1	2
bendiocarb	—	2	—	1	3	6
carbofuran	3	10	—	1	14	20
diazinon	—	—	—	2	2	2
disulfoton	—	1	—	—	1	1
famphur	1	—	—	—	1	2
fenthion	—	26	—	—	26	36
malathion	—	5	—	1	6	7
mevinphos	—	44	—	—	44	56
phorate	1	1	—	—	2	2
phosmet	—	1	—	—	1	1
propetamphos	—	—	—	1	1	1
Totals	5	89	—	7	102	136

Table 4. Summary of pesticides implicated in Canadian raptor kills (1985–95) according to whether they are thought to have been the results of labeled use, abuse, spill or where the use pattern was unknown.

	No. Incidents					
	Labeled Use	Abuse	Spill	Unknown Use	Total	Minimum No. Birds
Pesticide						
azinphos methyl	—	—	—	3	3	3
carbofuran	3	6	—	—	9	28
fensulfothion	1	—	—	—	1	3
fenthion	—	1	—	1	2	3
fonophos	8	—	—	—	8	9
parathion	—	—	—	4	4	4
phorate	3	2	—	—	5	34
terbufos	3	—	—	—	3	3
unknown OP	—	—	—	4	4	4
unknown CB	—	1	—	1	2	3
unknown OP or CB	—	1	—	16	17	18
Mixtures						
carbofuran and terbufos	—	1	—	—	1	4
phorate and ethion	1	—	—	—	1	1
phorate and methamidophos	2	—	—	—	2	4
terbufos and pirimicarb	1	—	—	—	1	1
Totals	22	12	—	29	63	122

treatment of warble fly in cattle until June 1994 and may have been used historically to treat sheep. Therefore, any presence of lamb's wool and fenthion in a British raptor automatically precipitated a diagnosis of abuse whether fenthion was used with the willful intention of killing raptors or whether it represented an unregistered attempt to kill ectoparasites in sheep. Nevertheless, the frequent presence of bait material as well as the frequent use of products clearly not labeled for crops grown in the area where most of the incidents occurred (e.g., the case for most mevinphos incidents) did indicate that most raptor incidents in the U.K. were the result of deliberate abuse. Spierenburg et al. (1990) reached a similar conclusion in the Netherlands following a review of 143 poisoning incidents occurring between 1975–88. In France, Berny (pers. comm.) also identified abuse as a major cause of incidents following a review of approximately 150 poisoning incidents investigated between 1991–96. Although most cases of deliberate abuse resulted from attempts to kill wildlife regarded as pests, the use of pesticides in poaching wildlife for human consumption may also be endemic in some areas. In some cases, game birds are targeted and raptors are secondarily poisoned and, in others, raptors are targeted directly. For example, both situations have been recorded in South Africa where vultures were sought after as a source of traditional medicine (van Jaarsveld 1987, Fourie et al. 1996, Verdoorn in press). The poisoning of ponds and waterholes with pesticides is used to harvest game species in Southeast Asia (Thiollay pers. comm.).

In contrast, pesticide abuse is thought to be less prevalent in North America. In his review of U.S. poisoning incidents, Grue et al. (1983) documented five cases of abuse relative to 26 cases of unintentional poisoning with OP pesticides. No raptors were found in any of these incidents. We estimated that, between 1985–94, there were 73 reported abuse cases relative to 64 labeled-use incidents for raptors specifically (Table 2). In Canada, labeled cases outnumbered abuse cases by a 2:1 ratio. In fact, circumstances surrounding most of the cases in the unknown category were highly suggestive of labeled use. Where ChE inhibitors were concerned, raptors in North America were at least as likely to be killed from a labeled pesticide use than from a willful attempt to poison them or some other vertebrate. One of our goals was to explore the apparent discrepancy between North America and

Table 5. Breakdown of U.S. cases involving the deaths of raptors from pesticides.

	Number of Individuals				
Species	Labeled Uses	Abuses	Use Unknown	Spills	Total
Turkey Vulture	—	8	2	1	11
Black Vulture	—	61	—	—	61
Osprey	—	—	2	—	2
White-tailed Kite	1	—	—	—	1
Mississippi Kite	17	—	—	—	17
Bald Eagle	31	87	125	—	243
Hen (Northern) Harrier	7	6	1	—	14
Sharp-shinned Hawk	2	—	—	—	2
Cooper's Hawk	9	—	3	—	12
Red-shouldered Hawk	—	—	2	—	2
Swainson's Hawk	20	—	—	—	20
Ferruginous Hawk	—	3	—	—	3
Rough-legged Hawk	1	—	—	—	1
Red-tailed Hawk	57	47	29	—	133
Golden Eagle	—	125	19	—	144
Unidentified hawk	0	8	—	1	9
American Kestrel	3	—	1	—	4
Prairie Falcon	—	1	—	—	1
Peregrine Falcon	5	—	1	—	6
Barn Owl	—	—	1	1	2
Short-eared Owl	1	—	—	—	1
Great Horned Owl	8	5	5	—	18
Barred Owl	4	—	1	—	5
Snowy Owl	2	—	1	—	3
Eastern Screech Owl	3	—	1	—	4
Unidentified owl	10	5	—	—	15
Totals	181	356	194	3	736

Table 6. Breakdown of Canadian cases involving the deaths of raptors from pesticides.

	Number of Individuals				
Species	Labeled Uses	Abuses	Use Unknown	Spills	Total
Bald Eagle	47	17	—	—	64
Hen (Northern) Harrier	30	—	—	—	30
Red-tailed Hawk	12	12	—	—	24
Golden Eagle	—	4	—	—	4
Rough-legged Hawk	1	—	—	—	1
Peregrine Falcon	1	—	—	—	1
Snowy Owl	1	—	—	—	1
Unidentified owl	—	—	1	—	1
Totals	92	33	1	0	126

Table 7. Breakdown of U.K. cases involving the deaths of raptors from pesticides.

	Number of Individuals				
Species	Labeled Uses	Abuses	Use Unknown	Spills	Total
Red Kite	1	23	5	—	29
Marsh Harrier	—	3	—	—	3
Hen Harrier	—	1	—	—	1
Sparrowhawk	—	5	—	—	5
Buzzard	4	64	3	—	71
Golden Eagle	—	5	—	—	5
Common Kestrel	—	4	—	—	4
Peregrine Falcon	—	12	2	—	14
Little Owl	2	—	—	—	2
Tawny Owl	—	2	—	—	2
Totals	7	119	10	—	136

Europe in order to better understand why poisonings occur. Of course, both in North America and Europe, pesticides and chemicals other than ChE inhibitors have been used in abuse cases. These include strychnine, thallium sulfate, alpha-chloralose, cyanide and sodium fluoroacetate (Compound 1080).

Not all species were as likely to suffer the brunt of pesticide abuse. The high vulnerability of the Common Buzzard (*Buteo buteo*) in Britain has already been reviewed (Brown et al. 1977, Cadbury 1980, Elliott and Avery 1991). Our review indicated that this species continued to be targeted. In the Netherlands, Red Kites (*Milvus milvus*) had the most frequent diagnosis of poisoning (as a proportion of reported incidents for each species), although more Common Buzzards and Goshawks (*Accipiter gentilis*) were found poisoned (Spierenburg et al. 1990). Unfortunately, that source did not provide the proportion of abuse cases by species. In North America, the Golden Eagle appeared to be almost always killed by abuse (Tables 5, 6). This is likely because Golden Eagle habitat seldom overlaps with cropland. Most kills were recorded in the western U.S. in association with attempts to kill eagles and/or coyotes. Allen et al. (1996) described how a liquid formulation of carbofuran applied on sheep carcasses to kill coyotes persisted for at least two months at high enough concentration to kill Bald Eagles that fed directly on the sheep as well as a Red-tailed Hawk which fed on a European Starling (*Sturnus vulgaris*) which also became contaminated after contact with the sheep meat. The Red-tailed Hawk was one of several species equally likely to be recorded following an abuse case or labeled use. Many other species, especially those that are less prone to scavenging and therefore to taking baits, were more frequently encountered in cases involving labeled uses. This was most notable for accipiters and most owl, falcon and kite species.

Pesticides employed in abuse cases undoubtedly reflected availability as well as toxicity to the intended victim. Carbofuran was widely available in several formulations and registered for a large number of crops. This single pesticide accounted for 75% of all known OP and CB abuse cases in the U.S. and 50% of Canadian cases (Tables 2, 4). In the U.K., mevinphos and fenthion accounted for more than 80% of abuse cases over the same period (Table 3). Older abuse incidents where the intent was to control songbirds often involved parathion-treated seed, both in North America (Stone et al. 1984) and Europe (Smit et al. 1986). The virtual absence of parathion from the more recent record probably reflected its reduced use. There was evidence that, where registered, monocrotophos was a popular bird control chemical. This was the case in South Africa (Fourie et al. 1996). A recent (1997) use of monocrotophos baits in Argentina killed an estimated 63 000 doves in cereal fields (Zaccagnini pers. comm.). Most of the birds killed were Eared Doves (*Zenaida auriculata*) with other dove and small granivorous bird species. Fifteen Barn Owls (*Tyto alba*) were also found dead in that incident.

Main Routes of Exposure for Raptors from Labeled Use. Consumption of Contaminated Inver-

tebrates. Many species of raptors were killed through the consumption of contaminated invertebrates. Insectivory is important to many raptor species. Of the 237 accipitrids recognized worldwide, 56 (24%) are exclusively or largely insectivorous whereas another 100 species (42%) are occasionally insectivorous (del Hoyo et al. 1994). There are numerous examples of species from the Northern Hemisphere which specialize on insects on the wintering grounds. European species such as Black Kites (*Milvus migrans*) feed on locusts in the Sahel or southern Africa and North American Swainson's Hawks that historically fed on locusts now eat grasshoppers and other insect species in the Argentine pampas. Because most OP and CB compounds are used as insecticides, consumption of contaminated insects is an important risk factor to consider for many species. The Swainson's Hawk may have been particularly vulnerable because of its apparent specialization on pests during outbreaks in agricultural crops. Incidents occurred not only in association with grasshopper control, but also in cotton and corn (maize) fields. In a cornfield, a kill was reported when they were consuming beetle larvae. They have also been reported to dive into mature corn to take caterpillars (Woodbridge pers. comm.).

Consumption of Freshly-sprayed Insects. The most obvious exposure situation was where freshly-sprayed insects are consumed directly by raptors. Large numbers of Swainson's Hawks died following grasshopper control in Argentina (Woodbridge et al. 1995). During the 1995–96 austral summer, as many as 3000 birds were killed in a single incident and at least 18 different incidents were witnessed for a total of about 5000 birds (Canavelli and Zaccagnini 1996). Based on an extrapolation of the area searched for kills and assuming all kills were located (an unlikely assumption which provides for a very conservative estimate), it was estimated that the 1995–96 mortality exceeded 5% of the total population of this species or more than 20 000 birds, largely because of the use of the organophosphate insecticide monocrotophos (Goldstein et al. 1996, Goldstein 1997). One incident was also thought to be caused by dimethoate but it could not be confirmed chemically. A smaller number of kills resulting from monocrotophos use continued to be reported in the 1996–97 and 1997–98 austral summers (Zaccagnini pers. comm.). Franson (1994) documented 16–18 Mississippi Kites (*Ictinia mississippiensis*) that died following the ingestion of caterpillars taken from a cotton field sprayed with parathion. The kill was reported because the birds died on a nearby golf course pointing out the chance element in any bird kill being uncovered. Fox et al. (1989) documented the disappearance of Burrowing Owls (*Athene cunicularia*) following spray applications of carbofuran (but not carbaryl, a grasshopper insecticide of lower acute toxicity) for grasshopper control. However, it was not determined whether exposure was through consumption of treated grasshoppers (the most likely hypothesis) or small mammals, another possible food source. Unfortunately, no carcasses were recovered for analysis. It was noteworthy that the rate of application of carbofuran implicated in the owl's disappearance was one of the lowest rates registered anywhere in the world (132 g.a.i./ha). Insecticides used for grasshopper spraying must be of low acute toxicity because of the importance of this food source for a large number of bird species including raptors.

Consumption of Invertebrates Contaminated by Granular Insecticides or Seed Treatments. Granular insecticides are extremely concentrated sources of insecticides. Granular products are a known problem when ingested by birds when perhaps they mistake them for grit or for a novel food source. The granular insecticide carbofuran has also been ingested by raptors such as Red-shouldered Hawks (*Buteo lineatus*) when the granules accidentally adhered to earthworms (Balcomb 1983). Even when granules were washed away, substantial residue levels remained. Only a few U.S. incidents clearly resulted from the direct ingestion of invertebrates contaminated by pesticide formulations other than sprays. In one incident in Texas in 1996 (data submitted by the manufacturer to the USEPA through mandatory adverse effect reporting regulations), 20 Swainson's Hawks were poisoned after ingesting grubs of the southern masked chafer (*Cyclocephala lurida*) contaminated with a granular formulation of terbufos (Counter 15G) used on seed corn. The birds picked up insects brought to the surface by high soil moisture and planting operations. High moisture conditions resulted in poor furrow closure. Granules were probably ingested directly from the soil because grubs were not found in the gastrointestinal tracts of the birds. In another incident in Texas in 1993, 20 Swainson's Hawks were found poisoned (19 died, one was rehabilitated and released) after feeding on an insect pest of cotton seedlings. The cotton seed had been treated at the sales outlet with the OP disulfoton and the seedlings were approximately 10–13 cm in height when the incident occurred (Hamilton pers. comm.). To our knowledge, this is the only documented case where a systemic insecticide passed through crop plants to grazing insects in sufficient quantity to then kill birds.

In the U.K., few kills resulted from labeled pesticide use, but three of four incidents clearly associated with labeled use were caused by granular carbofuran (Table 3) and two of the three involved earthworm ingestion and Common Buzzards. Several kills of earthworm-feeding Common Buzzards were also documented in Switzerland following the use of carbofuran in sugar beet fields; both Black and Red Kites are thought to have been similarly poisoned (Dietrich et al. 1995). The risk to birds may be higher for CBs like carbofuran because this class of insecticides is particularly toxic to earthworms. Earthworms exposed to CB products exhibit violent coiling behavior at the soil surface which is likely to attract predators. Because of their reliance on earthworms, buzzards and kites are likely to be affected more broadly in Europe. For example, Berny (1993) documented kite poisoning through earthworm consumption in France.

Secondary Poisoning Through Consumption of Vertebrates. In its strictest definition, secondary poisoning is the passing of residues assimilated into one animal tissue into another animal. This was the standard way in which lipophilic OC insecticides accumulated in food chains. The USEPA refers to secondary poisoning as residues being passed from vertebrate to vertebrate without regard to the exact location of these residues (Urban and Cook 1986). This is the most practical definition and the one we used. It is likely that most cases of 'secondary poisoning' involving OP and CB pesticides do not involve residues assimilated in the tissues of the primary kill. In most cases, residues are transferred to predators or scavengers when the gut contents are ingested or when surface (e.g., feather or foot) residues are ingested or transferred during prey handling. However, Hill and Mendenhall (1980) showed that sufficient quantities of the OP famphur could pass from the gut to post-absorptive tissues in dosed quail to induce both plasma and brain ChE inhibition in Barn Owls.

For many raptor species, carrion represents most of their total food intake, at least during some portions of the year. For European raptors, these include Common Buzzards, Red Kites and Golden Eagles (Barton and Houston 1994a). Raptors need not scavenge to be exposed to contaminated prey. Hunt et al. (1991) found that House Sparrows (*Passer domesticus*) exposed to lethal doses of fenthion through their feet were mobile for up to four hours postexposure and, as the birds became gradually incapacitated over that period, they were 16 times more likely to be captured by American Kestrels (*Falco sparverius*) than their uncontaminated flock mates (Hunt et al. 1992).

Information on whether raptors eviscerate their prey in the wild is difficult to obtain, yet this is one of the most critical risk factors affecting the likelihood of secondary poisoning from ChE-inhibiting pesticides. Fat is the most energetically-valuable tissue in a carcass (Barton and Houston 1994b). Raptors are therefore likely to seek mesenteric fat attached to the gastrointestinal tract. On the other hand, it may be energetically inefficient to ingest large quantities of green forage contained in the gastrointestinal tracts of prey. Burrowing Owls eviscerated ground squirrels before consuming them (James et al. 1990) which greatly reduced their risk of secondary poisoning from strychnine baits. Despite the many waterfowl kills recorded from diazinon use on turf (Stone and Gradoni 1985, Frank et al. 1991), we were unable to find any documentation of secondary poisoning associated with those kills. However, this may also have been a function of the habitat and a paucity of scavengers associated with turfed areas. Under different circumstances, consumption of waterfowl gut contents represents a common route via which granular insecticides are passed on to scavengers. Hiraldo et al. (1991) described Red Kites, Hen Harriers (*Circus cyaneus*), Imperial Eagles (*Aquila heliaca*) and Common Buzzards, as well as several vulture species at goose carcasses in Spain. They ate muscle as well as viscera, but no mention was made of how the gut contents were handled.

Granular insecticides. The most common form of secondary poisoning in raptors was seen following the use of granular insecticides. Granular insecticides are highly concentrated forms of pesticides (generally 5–20% insecticide by weight) which are often implicated in killing songbirds, shorebirds and waterfowl, as well as small mammals. Kills are characterized by a slug of concentrated granular material generally found in the gastrointestinal tract of the primary kill. Granular insecticides are particularly attractive to songbirds, either as grit or as food, and there have been several studies which attempted to better characterize the active uptake process (Best and Fischer 1992). Typically, secondary kills which resulted from consumption of contaminated songbirds occurred at the time or soon after the time of insecticide application (often at seeding). Granular carbofuran was frequently implicated in this form of secondary kill. Investigations have documented carbofuran incidents in more crops and exposure situations than any other product, which is perhaps a reflection of this insecticide's broad use as well as its high inherent toxicity. Several incidents were documented in corn (maize), grapes, winter wheat, cole crops and tree farms. Bald Eagles, hawks, Hen Harriers, accipiters and owls have been poisoned (Table 4).

Bucknell (1970, 1971) and Mills (1973) described extensive mortality of harriers in New Zealand which died after pastures were treated with fensulfothion (5% granule) and parathion (10% granule). The granules were dyed green in an effort to make them less conspicuous to birds, and the investigators saw very few granules in stomach contents suggesting that the harriers were poisoned by scavenging birds (primarily magpies and gulls) which had themselves been poisoned by contaminated grass grubs. Evidence that the granules had released most of their active ingredients when the kills occurred means that this route of exposure was like that seen following spray applications.

Another frequent but less commonly recognized route of exposure to granular insecticides is passive uptake generally involving waterfowl species. Typically, waterfowl are exposed to granular insecticides when they sift sediments and crop residues in puddles or waterlogged soils. Extensive kills of waterfowl have occurred in potato and root crops in British Columbia, Canada as well as in partially flooded corn, winter wheat and rice fields in the U.S. (Table 8). One interesting thing about these poisonings is that they occur at different times of the year, often several months postharvest. In British Columbia, Canada, granular insecticides have had unexpected persistence (Wilson unpubl.). Several spring-applied products persisted in sufficient concentration to kill waterfowl and raptors secondarily throughout the following fall and winter. Enhanced persistence was attributed to soils of low pH, but the waterlogged nature of the soils may also have been a factor.

Buck et al. (1986) followed Great Horned Owls (*Bubo virginianus*) using radiotelemetry in an Iowa farming area where granular formulations of the insecticides terbufos and chlorpyrifos were used and where small mammals were known to have been exposed and affected by the insecticides. They could not conclusively demonstrate exposure because the owls preferentially foraged in non-treated areas.

Treated Seeds. Seed treatment is defined as the application of a pesticide to the seed prior to planting. This can be a simple surface treatment or seeds can undergo a pelletization process where several combinations of pesticides, fertilizers or inoculates can be applied in an inert waxy covering to the seed. Treated seeds represent another potential route through which high residues of insecticides can be transferred via ingestion of viscera from primarily kills. Historically, the use of OCs such as aldrin, heptachlor and mercurial compounds as seed treatments have been responsible for extensive secondary poisoning of raptors in North America and Europe. In North America, most seed is now treated with gamma HCH (lindane). In Europe, the trend has been to use OP and CB seed treatment chemicals, and we believe there will be a growing use of ChE inhibitors for this use in North America. Despite documentation of primary kills in the U.K. (e.g., geese from carbophenothion and pigeons from fonofos and chlorfenvinphos [Greig-Smith 1987b]), there have been no reports of secondary poisoning in these incidents.

Assimilated and Surface Residues from a Liquid Spray Application. In the case of highly-toxic insecticides, the chemical need not be present as concentrated granular material or seed treatment to secondarily affect raptors. There were documented instances with carbofuran, monocrotophos and parathion where residues were present in sufficiently high concentration in vertebrate prey following a spray application to cause secondary poisoning (Table 9). In registrant-sponsored field studies of carbofuran in both corn (at 1.1 kg a.i./ha) and alfalfa (at 0.55 kg a.i./ha), immobilized Hen Harriers were observed. One bird had been feeding on a rabbit (Mineau 1993). Similarly, several U.S. incidents were recorded in vineyards following the application of carbofuran to drip irrigation water when songbirds were attracted to the irrigation water for drinking and were then captured or scavenged (Table 9). Monocrotophos kills recorded in Israel (Mendelssohn and Paz 1977) were among the earliest kills of raptors ever recorded following

Table 8. Documented cases of raptor poisoning from the approved (labeled) used of granular insecticides or seed treatment, in or on invertebrate or vertebrate prey.

GRANULAR INSECTICIDE	CROP	PRIMARY KILL SPECIES	SECONDARY KILL SPECIES	REFERENCES
carbofuran	corn (maize)	songbirds, pigeons, raccoon[a], waterfowl, earthworms	Bald Eagle American Kestrel Red-tailed Hawk Red-shouldered Hawk Hen Harrier Short-eared Owl Vulture sp. (S. Africa)	1[b], 2, 3, 4, 5
	rice	waterfowl	Red-tailed Hawk Northern Harrier	6
	grapes	songbirds	Cooper's Hawk Sharp-shinned Hawk American Kestrel Red-tailed Hawk Northern Harrier	1[b]
	winter wheat	fox[a]	Red-tailed Hawk Bald Eagle	1[b]
	pine plantations	small mammals	Red-tailed Hawk Bald Eagle	1[b]
	potatoes/root crops	waterfowl	Bald Eagle Red-tailed Hawk	7
	cauliflower	earthworms	Little Owl	8
	sugar beet	earthworms	Common Buzzard (Black and Red Kites also suspected)	9
fensulfothion	pasture	songbirds, small mammals (hedgehog), gulls, magpies	Pacific Marsh-harrier	10, 11, 12
	potatoes/root crops	waterfowl	Bald Eagle Red-tailed Hawk	7
parathion	pasture	magpies, gulls, songbirds, small mammals	Pacific Marsh-harrier	12
phorate	winter wheat	waterfowl	Bald Eagle Golden Eagle Northern Harrier Great Horned Owl Red-tailed Hawk	1[b], 13
	potatoes/root crops	waterfowl	Bald Eagle Red-tailed Hawk	14
terbufos	potatoes/root crops	waterfowl	Bald Eagle Red-tailed Hawk	15[b]
	corn (maize)	beetle larvae	Swainson's Hawk	1[b]
fonofos	potatoes/root crops	waterfowl	Bald Eagle Red-tailed Hawk	15[b]
disulfoton	cotton	unidentified insect pest	Swainson's Hawk	16

1 U.S. incident data.
2 Balcomb (1983).
3 Booth et al. (1983).
4 Stinson et al. (1994).
5 Ledger in Mineau (1993).
6 Littrell (1988).
7 Elliott et al. (1996).

Table 8. Continued.

8. Fletcher et al. (1989).
9. Dietrich et al. (1995).
10. Bucknell (1970).
11. Bucknell (1971).
12. Mills (1973).
13. C. Sowards and D. Fries, U.S. Fish and Wildlife Service, pers. comm.
14. Elliott et al. (1997).
15. Canada incident data.
16. Hamilton pers. comm.

[a] It is believed that the planters/seeders deposited granules on carcasses which were then scavenged. The mammals indicated as primary kills were probably not killed by the pesticide.

[b] The designation U.S. incident data or Canada incident data refers to cases tabulated in the current review but not yet published

the use of ChE-inhibiting insecticides. Starting in 1975, farmers attempted to control voles in alfalfa fields with aerial applications of monocrotophos, often at rates higher than prescribed for insect control. Consequences for wildlife in general and raptors in particular were dramatic. Mass mortality of larks, thrushes, chaffinches, buntings and lapwings were noted as were dead jungle cats and wild pigs. Following a 600 ha application in 1975–76, authorities recovered 219 individual raptors of 13 species dead or paralyzed including Greater Spotted (*Aquila clanga*), Lesser Spotted (*Aquila pomarina*) and Imperial Eagles, Long-legged (*Buteo rufinus*) and Common Buzzards, Black Kites, Western Marsh (*Circus aeruginosus*), Hen and Pallid (*C. macrourus*) Harriers, Common Kestrel and Short-eared (*Asio flammeus*), Long-eared (*A. otus*) and Barn Owls. It was estimated that the total kill was easily twice as high as the number of birds collected (Mendelssohn and Paz 1977). The usual wintering populations of birds were thought to be supplemented by migrants. The carnage continued in 1976–77 on a similar scale with White-tailed Eagle (*Haliaeetus albicilla*), Merlin (*Falco columbarius*), Eurasian Sparrowhawk and Eurasian Eagle Owl (*Bubo bubo*) added to the list. Spraying was reduced in the winters 1977–79 although a number of raptors were also found dead (Mendelssohn et al. 1979). This use of monocrotophos apparently still occurs (Shlosberg pers. comm.). Monocrotophos when used at the lower rate of 0.5 kg a.i./ha against cutworm larvae in wheat caused the death of Short-eared Owls and a Northern Harrier, presumably when they scavenged the multitude of songbirds also found dead or debilitated (Benson and Baker 1971).

Of course, raptors manipulate their vertebrate prey extensively, whether in the process of killing,

Table 9. Documented cases of secondary poisoning in raptors resulting from the approved (labeled) use of liquid insecticide sprays and consumption of vertebrate prey.

LIQUID INSECTICIDE	CROP	PRIMARY KILL SPECIES	SECONDARY KILL SPECIES	REFERENCES
carbofuran	vineyard	songbirds, small mammals	Red-tailed Hawk Sharp-shinned Hawk	U.S. incident data
	corn	?	Northern Harrier	FMC 1989 in Mineau (1993)
	alfalfa	songbirds, rabbit	Northern Harrier White-tailed Kite	U.S. incident data FMC 1989 in Mineau (1993)
parathion	pasture	lapwings and others	Red kites	Smit et al. (1986) Over (1989)
	wetlands	Quelea	many species—see section 2.2.4	see text
monocrotophos	wheat	songbirds, pheasant, small mammals	Northern Harrier Short-eared Owl	Benson and Baker (1971)
fenthion	wetlands	Quelea	many species—see section 2.2.4	see text

plucking or eviscerating. The primary vertebrate kills, especially small birds and mammals, can carry an appreciable load of residues on their fur or feathers from being in contact with an aerosol or entering a freshly-sprayed field. It is difficult to conclude whether secondary poisoning is a result of consuming viscera or surface residues or both.

Avicides. Some bird control programs use ChE inhibitors and it is not surprising that raptors attracted to the easy source of food are killed. In North America, the main use of ChE inhibitors for bird control has been the Rid-a-Bird™ perch. It consists of a hollow mesh perch with a wick soaked in a solution of 11% fenthion. Pest birds are exposed through their feet and undersides when they land on a perch. The perches are labeled for the control of European Starlings, House Sparrows and pigeons in North America. Hunt et al. (1991, 1992) experimentally demonstrated the risk of secondary poisoning from the use of fenthion in Rid-a-Bird™ perches. A single contaminated sparrow proved lethal to 9 of 10 kestrels. Furthermore, they also demonstrated that exposed sparrows were more than 16 times more likely to be captured by American Kestrels than their unexposed flockmates.

At least 21 cases of fenthion poisoning involving Rid-a-Bird™ perches were reported from 1984–94 (Table 10). In a third of the cases, the use of the perches was not positively established or was still under investigation. Cases continued to be reported in 1995 and 1996.

A 1986 Illinois incident involving trained and feral Red-tailed Hawks (Wenneborg 1986) resulted in symptoms that began six hours after consumption of a single starling and continuing for at least 24 hr despite repeated treatments with atropine sulfate and protopam chloride. Only when birds regurgitated pellets did recovery begin. Another incident involved a falconry-trained Cooper's Hawk (*Accipiter cooperii,* Keltsch-Richter 1989). Lacombe et al. (1994) reported that perches were suspected in Merlin kills in western Canada, but evidence was not available.

Fenthion has also been one of the main avicides used in the control of Red-billed Quelea (*Quelea quelea*) in several African countries (Keith and Bruggers 1998). Typically, quelea roosts are sprayed by aircraft at sundown but ground applications to crops, roosts and water holes are also made (Thomsett 1987). Thomsett reported that 41 dead or dying raptors were found shortly after a 1984 control program in Kenya. They included Cape (*Bubo capensis*) and Verreaux's (*B. lacteus*) Eagle Owls, Secretary Bird (*Sagittarius serpentarius*), Gabar Goshawk (*Micronisus gabar*), Augur (*Buteo augur*) and Lizard (*Kaupifalco monogrammicus*) Buzzards, Tawny Eagle (*Aquila rapax*) and Black-shouldered (*Elanus caeruleus*) and Swallow-tailed Kites (*Elanoides forficatus*). Quelea were observed dying up to nine days post-spray, carrying the impact farther afield. According to Bruggers et al. (1989), Thomsett's unpublished field report extends this period to 19 days. The raptors died either from capturing dead or debilitated quelea and, in some cases, were exposed directly. Surveys conducted before and after the spray indicate that the usually plentiful raptor community had been almost completely eradicated.

As a result of these reports, a study was initiated in Kenya in 1985 (Bruggers et al. 1989). Two colonies of quelea (50 ha in total) were treated with fenthion under rigorously controlled conditions. Results were similar and, although some quelea died by the morning following spray, some died up to seven days post-spray. Affected quelea were found over 35 km^2 surrounding one of the colonies. Twenty-three raptors of six species including Tawny and Bateleur (*Terathopius ecaudatus*) Eagles, Gabar and Pale-chanting (*Melierax canorus*) Goshawks, Pygmy Falcons (*Polihierax semitorquatus*) and Pearl-spotted Owlets (*Glaucidium perlatum*) were captured before the spray and fitted with radio-transmitters. Post-spray, an instrumented Pearl-spotted Owlet and Tawny Eagle were found moribund and sacrificed. A sick Pygmy Falcon was also collected. A second Tawny Eagle was found debilitated but was not collected. Based on ChE data, at least 16 of the 23 raptors were exposed. In all, 17 species other than quelea were found dying after spraying and this, despite overnight scavenging rates as high as 90% at one site. Residues on quelea were found to be sufficiently high to kill most raptor species. Following applications to two small wetlands (5 ha and 0.5 ha) in Kenya in 1988, Keith et al. (1994) reported 84 birds of 20 species dead or debilitated. However, the impact on raptors was not evaluated because few were seen in the vicinity. Callahan and Ferreira (1989) reported finding six dead or incapacitated Common Buzzards following treatment of a 20 ha quelea colony in South Africa, but this did not represent an exhaustive survey.

Fenthion is not the only OP insecticide to be used for quelea control. Thiollay (1975), reporting on the use of ethyl parathion in Mali, counted 400 dead Black Kites following treatment of a single 8-ha quelea colony. Both European (*M. m. migrans*) and African (*M. m. parasitus*) subspecies were killed. He also made reference to a large number of other diurnal and nocturnal raptors associated with quelea colonies and estimated that between 92–100% of nontarget species (whether or not they were quelea predators or scavengers) were killed by the treatments compared to 38% of young and 2% of adult queleas. In South Africa, spraying of quelea colonies prior to 1986 was primarily with ethyl parathion (Tarboton 1987). One monitored spray yielded 16 Tawny and Steppe (*Aquila nipalensis*) Eagles as well as 46 Black Kites. A Wahlberg's Eagle (*Aquila wahlbergi*) was also reported by Tarboton (1987) as being poisoned in a separate spray.

Topical Treatment of Livestock and 'Medicated' Livestock Feed. One of the earliest documented incidents of secondary poisoning by a ChE inhibitor proved to be also one of the most intriguing. It concerned the use of the OP famphur poured on the back of livestock to control warble fly larval parasites (grubs) systemically. According to Henny et al. (1985), ranchers had begun reporting kills of magpies associated with the use of famphur as early as 1973, shortly after its introduction to the U.S. market. The first formal account of famphur poisoning documented mortality of Black-billed Magpies (*Pica pica*), European Robins (*Erithacus rubecula*) and Dunnock (*Prunella modularis*) in Great Britain (Felton et al. 1981). It was noteworthy that similar problems with fenthion used for warble fly treatment were reported the very same year in Canada (Hanson and Howell 1981). Henny et al. (1985, 1987) and Franson et al. (1985) described secondary poisoning of raptors associated with primary kills of Black-billed Magpies and European Starlings. Henny et al. (1985, 1987) found that magpies were poisoned when they ingested hair from topically-treated cattle. Red-tailed Hawks scavenging the magpies died from secondary poisoning and a case of tertiary poisoning of a Great-Horned Owl scavenging one of the dead hawks was even documented.

Despite the detailed investigative work of Henny and colleagues, the incident record for famphur remains complex and confusing. Not all incidents involved magpies. Several cases of secondary poisoning appeared to have originated from blackbirds or starlings that had fed on treated grain. Application of pesticides to grain is a common tactic for those intent on abusing pesticides to control pest birds, and famphur has been used for this purpose around farm fields (White et al. 1989). In many cases, however, pesticide abuse was technically inseparable from normal labeled use of the product because the OP can legally be delivered to cattle through their feed although this is apparently not the favored technique. Table 11 represents an attempt to categorize U.S. famphur incidents on the basis of investigation reports and necropsy information largely on content of the bird's crop. One consequence of this complexity in the incident record was that relatively few incidents could be categorized as clear abuse cases or clear labeled-use cases. Also, in early years, incident investigators did not know that famphur could persist in the hair of treated cattle for >100 d. Therefore, eagles that died weeks or months after cattle were treated were automatically assumed to be abuse cases. In Britain, the use of famphur as a topical insecticide was linked to the death of magpies on several occasions (Felton et al. 1981, Fletcher et al. 1990) and there was a probable case of raptor secondary poisoning on record. Two Common Buzzards were found with residues of famphur in one incident in 1993. Small birds were found in their gizzards (Fletcher et al. 1994).

Fewer cases were recorded with the use of fenthion used as a 'pour on,' but this may simply have reflected the extent of use. Henny et al. (1987) described a number of Bald Eagles killed by fenthion obtained from having scavenged small pigs from a farm where sows were treated. It was not clear how the fenthion had been transferred from sow to piglets although abuse was not indicated. In the U.K., fenthion was approved for the control of warble fly larvae in cattle, but this approval was withdrawn in 1994. Between 1985–94, 26 cases of fenthion poisoning were reported in Britain. Because some baits were found in some of the incidents and most of the incidents occurred in areas of largely sheep rather than cattle farming, all cases were ascribed to abuse. In at least two cases, lamb flesh was confirmed in the ingesta. Fenthion never was registered to treat lambs and it was suspected that lamb carcasses were treated with fenthion to kill corvids. It was noteworthy that one of the two documented fenthion cases in Canada was the result of an attempt to control ectoparasites in lambs. Although categorized as a case of abuse (Table 4), there was no willful attempt to poison rap-

Table 10. U.S. kills caused or strongly suspected of being caused by use of the Rid-a-Bird™ perch with fenthion (1984–95). Sources: unpublished U.S. reports compiled for this review as well as Wenneborg (1986), Keltsch-Richter (1989), Franson et al. (1996) and Long (pers. comm.).

YEAR	STATE	SPECIES AFFECTED (NUMBER FOUND)	PEST SPECIES OR OTHER PRIMARY KILLS	SITE	NOTES
1986	IL	Great Horned Owl (4) Red-tailed Hawk* (1)	Starlings, Grackles, House Sparrows	Generating station	According to unconfirmed reports, at least 21 hawks and owls died in this incident.
1987	IL	Sharp-shinned Hawk (1) Red-tailed Hawk (10) Rough Legged Buzzard (10) Great Horned Owl (1) Barred Owl (1)	Starlings (primarily)	Oil refinery	
1988	IA	Eastern Screech Owl (1)	House Sparrows	NR	Owl was said to have landed on the perch.
1988	IL	Snowy Owl (1) Cooper's Hawk (1)	Starlings	Oil refinery	These occurred at the same site but represent different attempts to control pest birds.
1988	IL	Barred Owl (1) American Kestrel (1) Screech Owl (1)	Starlings	Oil refinery	
1989	WA	Short-eared Owl (1)	Starlings, Rock Doves	Industrial site	
1989	OH	Barred Owl (1)	Barn swallows	NR	
1989	IL	Cooper's Hawk* (1)	Starling	NR	Use of perches not established or under investigation.
1992	VA	Peregrine Falcon (1)	Rock Doves	Air Force Base	
1992	OH	Peregrine Falcon (1)	Rock Doves	City	Use of perches not established or under investigation.
1992	MO	Red-tailed Hawk* (1)	Rock Doves	Open land near airport	Use of perches not established or under investigation.
1992	IL	Cooper's Hawk (3) Hawks spp. (3) Owl spp. (6)	NR	Oil refinery	Another report of 2 Red-tailed hawks may be related to this kill.
1993	MO	Peregrine Falcon (1)	Unidentified bird	City	Use of perches not established or under investigation.
1993	MO	Great Horned Owl	Mourning Doves, Rock Doves	Correctional facility	Use of perches not established or under investigation.
1994	MO	American Kestrel (1)	NR	Bird near airport hangar	Use of perches not established or under investigation.
1994	MN	Peregrine Falcon (1)	Rock Doves	Residential driveway	Use of perches not established or under investigation.
1994	OK	Red-tailed Hawk (6) Barred Owl (1)	Starlings, American Robins	Feedlot	
1994	KS	Red-tailed Hawk (5) Screech Owl (1)	NR	NR	

Table 10. Continued.

YEAR	STATE	SPECIES AFFECTED (NUMBER FOUND)	PEST SPECIES OR OTHER PRIMARY KILLS	SITE	NOTES
1994	MN	Peregrine Falcon (1)	NR	City	
1994	MN	Peregrine Falcon (1)	NR	City	Found 16 km away from previous bird. May represent a single application site although perches used in several locations.

* Falconry bird.

tors and the user was not prosecuted (Bowes et al. 1992). McKenzie et al. (1996) diagnosed cases of poisoning of several scavenging species (although no raptors) in 1993–94 in Australia. Although fenthion was registered as a pour-on treatment for cattle, they were unable to trace the source of the chemical or to determine whether the cases might have resulted from malicious poisoning.

In 1992, one case involving a Red Kite and an unspecified use of diazinon was recorded in the U.K. where diazinon was approved as a sheep dip. Given the propensity of the kites to feed on lamb carcasses, this seemed a likely route of exposure although this could not be confirmed.

Also in 1992, a dead nestling Red Kite was found to have been exposed to propetamphos, another sheep dip approved for use in Britain (Fletcher et al. 1994). Because of the low residue level (0.05 mg/kg), the bird was not thought to have been willfully poisoned. Finally, a Red Kite was found poisoned by phosmet (Fletcher et al. 1991). This insecticide is approved for warble fly treatment in a variety of livestock; however, residue levels of 8300 mg/kg suggested deliberate poisoning rather than the birds having fed on the carcasses of treated livestock.

Dermal Exposure in Treated Areas. The potential for direct dermal exposure of raptors to pesticides is the same as for any other group of birds entering treated areas. Although relatively few data are available to assess the relative contribution of dermal exposure in most pesticide use situations, the dermal route is clearly important or even dominant in some cases (Mineau et al. 1990, Driver et al. 1991, Henderson et al. 1994, Shlosberg et al. 1994). There is one notable U.S. use pattern where dermal exposure clearly dominates, that being the exposure of raptors to insecticides applied in dormant oils to almond and stone fruit orchards in California. Many incidents and kills of Red-tailed hawks are known to have occurred in orchards. Hooper et al. (1989) live-trapped 12 Red-tailed Hawks in 1986 and 1987 and found 67% showing ChE inhibition. Following on this work, Fry et al.

Table 11. Summary of U.S. famphur incidents (1985–94) broken down by apparent crop content at necropsy.

NATURE OF INGESTA	ABUSE	LABELED USE	CIRCUMSTANCES UNKNOWN	TOTALS
grain and bird remains	5	—	4	9
magpie remains[a]	—	2	—	2
hair and bovine tissue	1	4	12	17
small mammal	—	—	1	1
bird remains	—	—	8	8
mixed bird and mammal remains	—	—	3	3
fish remains	1	—	—	1
unspecified crop contents	1	—	9	10
Totals	8	6	37	51

[a] Bird remains were only infrequently identified to species.

(1998) used radiotelemetry and pesticide-use data correlated with foot-wash residues and plasma ChE to assess the relative contributions of a number of different OP pesticides to the 'effective' exposure in Red-tailed and Red-shouldered Hawks using the orchards. Of the pesticides studied (ethyl parathion, diazinon, methidathion and chlorpyrifos), parathion contributed the most to the measured level of inhibition in the birds. Parathion use in dormant-oil sprays was canceled in December 1991. In more recent years (1993–94), a number of incidents have been associated with exposure of birds to the other three OP insecticides (Hosea pers. comm.). Most of the birds did not appear to die from toxicosis. For most, trauma such as electrocution, entanglement or impact was diagnosed as the proximate cause of death. Based on depressed ChE levels as well as pesticide residues extracted from feathers or foot washes, pesticides were frequently ascribed a contributory role only. Nevertheless, we included some of these incidents. A good analogy from a human perspective would be traffic accidents and impaired driving: the exact circumstances surrounding accidents are varied, yet the root cause is impairment. Continuing the analogy, the situation is made more complex by the fact that motor vehicle accidents occur even without alcohol. The role that ingesting contaminated prey may play in some of these incidents has not been assessed. Although foot and feather washes are routinely analyzed, crop contents are not.

RISK FACTORS CONTRIBUTING TO RAPTOR POISONING

We have discussed several risk factors in the context of exposure routes. Some of the more significant factors that result in raptor poisonings are insectivory and vermivory, opportunistic taking of debilitated prey, scavenging (especially if the gastrointestinal tracts are consumed), presence in agricultural areas, perceived status as pest species and flocking or other gregarious behavior at some part of the life cycle (e.g., a geographically-restricted breeding, migration or wintering area).

There are other risk factors of overarching importance, namely the toxicity of ChE inhibitors and the relative sensitivity of raptors to OP and CB pesticides.

Toxicity to Birds of In-use Pesticides. Poisoning incidents occur frequently because many ChE-inhibiting pesticides are acutely toxic to birds. Also, the importance of cholinergic systems is such that, even if exposure does not cause immediate death, many sublethal manifestations of exposure to ChE inhibitors can lead to reduced survival in exposed individuals (Grue et al. 1991). Based on their review of poisoning cases, Grue et al. (1983) concluded that a large proportion of incidents can be explained by toxicity and extent of use. Inherent in their conclusion is that exposure is inevitable, or at least difficult to limit in many cases. In light of this, we compared the use of ChE-inhibiting pesticides in the U.S. with that in the U.K since there appears to be a dramatic difference in the relative proportion of labeled-use cases to the total number of cases in these two jurisdictions (Table 12). Unfortunately, a similar comparison could not be made with Canada because there were no comprehensive statistics on pesticide use.

We assumed that the 1994 pesticide data were representative of the 1985–95 period summarized. It should be noted that pesticides not currently used on crops such as famphur and fenthion were excluded. We found that the use of ChE inhibitors (expressed as tons of a.i./ha of cropland) was almost three times higher in the U.S. than in the U.K. For the U.K., six compounds accounted for >85% of the total tonnage of ChE inhibitors used (Garthwaite et al. 1994). Of these, only aldicarb (8.2% of ChE-inhibiting tonnage) has an HD_5 (Hazardous $Dose_5$) value (the avian LD_{50} value calculated to be at the 5% lower tail of the distribution of all avian LD_{50} values with a 50% probability for that compound) <1 mg/kg (Table 13). By comparison, in the U.S., we included 16 pesticides in order to account for a similar proportion of the total tonnage of ChE-inhibitors (Gianessi 1995). Six of the 16 (or 32% of the total tonnage) were pesticides with an HD_5 <1 mg/kg. It was noteworthy that labeled use incidents in the U.K. (Table 3) were all associated with pesticides considered minor in that country but which are all major use products in the U.S. (carbofuran, phorate, famphur). We concluded that the proportionate difference in labeled vs. abuse cases in the two countries was a direct result of the products in use. There was a higher reliance in the U.S. on ChE-inhibiting insecticides having an extreme toxicity to birds.

A comparison of the absolute number of cases in the two countries was more difficult because reporting rates are known to differ. Given that 'unknown' cases in Tables 2 and 3 followed a similar labeled use to abuse proportion noted for cases where circumstances are known, national authori-

Table 12. Reported sales and intensity of use of organophosphate and CB pesticides for the U.S. and U.K. in 1994, top selling products and their toxicity to birds.

Country	Arable Land (Million ha)[1]	Tonnes ChE Inhibitors Used[2]	Intensity of ChE Inhib. Use Per ha	Top ChE-Inhibiting Insecticides in Crops Making Up >85% of the Total Tonnage	Tonnes	Avian HD_5 for 20 g Bird[2] (mg/kg)
U.S.	165	37,413	0.23 kg	chloropyrifos	6697	3.8
			a.i./ha	terbufos	3492	0.35
				methyl parathion	2704	2.5
				carbofuran	2314	0.055
				carbaryl	2073	49.0
				phorate	2020	0.21
				aldicarb	1825	0.46
				acephate	1538	23.0
				malathion	1532	152.0
				demethoate	1188	5.9
				azinphos methyl	1097	2.5
				fonofos	1076	4.1
				parathion	1051	0.42
				profenofos	936	N/A
				disulfoton	819	0.56
U.K.	6.99	571	0.082 kg	dimethoate	213	5.9
			a.i./ha	chlorpyrifos	133	3.8
				pirimicarb	50.6	7.2
				aldicarb	46.9	0.46
				triazophos	37.4	2.9
				demeton-S-methyl	11.7	8.3

[1] After Cobham and Rowe (1986).
[2] U.S. data from Gianessi (1995); U.K. data from Garthwaite et al. (1994).
[3] Updated from Baril et al. (1994), Mineau et al. (1996).

ties have documented, on average, about 12 labeled-use cases per year and 0.5 labeled-use cases per year in the U.S. and U.K., respectively. However, when expressed as cases/ton of OP or CB in use (Table 12), the number of reported labeled-use incidents was 2.8 times higher in the U.K. than in the U.S. which is counter to the trend expected. If we accept the relationship between the toxicity of in-use pesticides and the likelihood of labeled-use incidents, we need another reason to explain the difference. The most likely hypothesis is that U.S. incidents are under-reported by at least 2.8 times relative to Britain. A higher reporting rate in Britain could easily be explained by a combination of smaller field sizes, a higher human population density, a high level of interest in avian welfare and a long-standing incident investigation system. In fact, the difference in reporting rates is likely to be higher because we suspect a far higher number of labeled-use cases in the U.S. for every ton of ChE inhibitor used. However, it is also possible that the more intensive use of cropland by raptors in Britain increased the probability of exposure to even minor-use products.

The limitations of this analysis are readily apparent. Most important, we had no knowledge of the actual incident rate and could only compare the two countries in relative terms. Also, the comparison did not take into account the specific use patterns of the various products. Even low-use products such as fenthion used in Rid-a-Bird™ perches can have a measurable impact on the incident record. Finally, the analysis ignores differing biases in the two countries with respect to the reporting of raptor incidents.

Relative Sensitivity of Raptors to ChE Inhibitors. There was only very limited information on the senstitivity of raptors to ChE inhibitors relative to other birds. We (Mineau et al. 1996) showed that a significant degree of variance in interspecies sen-

Table 13. Acute toxicity data available for raptors compared to predicted (best fit) avian toxicity data for an average bird of the same size.

PESTICIDE	NO. AVAILABLE LD_{50}S	REGRESSION R SQUARE[a]	INTERCEPT (a)	SLOPE (b)	SPECIES	MEASURED LD_{50}	CALCULATED (BEST FIT) LD_{50}[b]
monocrotophos	24	0.77	−2.5603	0.9695	Golden Eagle	0.188[1]	2.1
					Screech Owl	1.5[2]	2.4
					American Kestrel	1.5[2]	2.4
fenthion	25	0.82	−2.8346	1.2802	Screech Owl	3.9[2]	6.1
					American Kestrel	1.4[2]	5.6
EPN	14	0.56	−2.8788	1.4327	Screech Owl	274[2]	12.0
					American Kestrel	4[2]	10.6
carbofuran	18	0.65	−2.9455	1.0787	American Kestrel	0.6[2]	1.7
					Screech Owl	1.9[2]	1.7
methyl parathion	10	0.86	−2.3540	1.1646	American Kestrel	3.1[3]	9.8

[a] Mineau et al. (1996). Proportion of variance explained by linear regression of the form: $Log(LD_{50}) = a + b$ (log weight in grams).

[b] Assuming mean (mixed sex) weight of 123 g for American Kestrel, 164 g for Screech Owl after Wiemeyer and Sparling (1991), and 4300 g for Golden Eagle after Dunning 1984.

1 Hudson et al. (1984).

2 Wiemeyer and Sparling (1991).

3 Rattner and Franson (1984).

sitivity to pesticides (based on a sample heavily weighed to ChE inhibitors) could be explained by allometric scaling and that, in general, large-bodied birds were less sensitive than small-bodied birds. This suggested that, when estimating the average sensitivity of birds to any given pesticide, their weights should be taken into account. Table 9 reviews measured acute toxicity data endpoints in raptors with projected values calculated from a 'best-fit' of all available avian data and the weight of the species. Although it is difficult to generalize from so few data points (only three raptor species, 10 species-chemical combinations), raptors appear to be more sensitive than birds of similar size in eight of 10 comparisons. One exception was the apparent insensitivity of Eastern Screech Owls to EPN. Our tentative finding is that raptors may indeed have an inherent sensitivity to ChE inhibitors, thereby justifying the use of the 95% protection level (the use of a calculated HD_5) when assessing the risk of ChE-inhibitors to raptors.

THE CONSERVATION ASPECTS OF RAPTOR POISONING INCIDENTS

It is generally recognized that bioaccumulation of OC pesticides has had a devastating effect on raptor populations, especially in the 1950s and 1960s at the height of their use (Newton 1979). It is important to recognize that the effect of these pesticides was two-fold, causing eggshell-thinning effects from DDE as well as direct poisoning from accumulated cyclodiene residues, principally aldrin and dieldrin used as seed treatments. The mortality of birds of breeding age from cyclodiene seed treatments had the most profound influence on the population dynamics of the Eurasian Sparrowhawk in Britain (Newton and Wyllie 1992). Adult mortality, especially in the spring, was probably additive because known density-dependent sources of natural mortality operated over the winter months. Similarly, the use of dieldrin for grasshopper spraying was the most important factor associated with declines of Merlins from Saskatchewan, Canada (Houston and Hodson 1997). Noer and Secher (1990) showed that a ban on hunting in Denmark rather than the coincidental decline in the use of OC insecticides was responsible for the 1970s increases in populations of Common Buzzards, Eurasian Sparrowhawks and Goshawks. Similarly, increases in mortality rates and not a decrease in reproductive success were thought to be responsible for the more recent declines in these species (Noer and

Secher 1990). It stands to reason that we should consider the potential of current pesticides to increase mortality rates in raptors, especially that of breeding adults.

In Britain, raptors have been poisoned with ChE-inhibiting pesticides and other chemicals (e.g., alphachloralose, strychnine) and they have been persecuted through nonchemical means. This persecution has played, and in some cases, continues to play, an important role in the population dynamics of several species. Historically, persecution led to the extirpations of the Goshawk, Marsh Harrier, Osprey (*Pandion haliaetus*) and White-tailed Eagle from the British Isles (British Trust for Ornithology et al. 1997). Currently, it is estimated that half of all Welsh Red Kites die prematurely from poison baits (Davis 1993). Between 1971–93, 44 Red Kites were confirmed to be illegally poisoned in the British Isles (Evans et al. 1997). The total breeding population in 1996 was estimated at 182 and, recently, birds have been introduced from Spanish stock. Persecution has also had a measurable effect on Golden Eagles and Hen Harriers in Scotland as well as Common Buzzards in western Britain (British Trust for Ornithology et al. 1997). In some cases, persecution may be preventing some species from regaining part of their former range (e.g., Common Buzzard, Elliott and Avery 1991). Although the availability of highly toxic pesticides undoubtedly exacerbates the persecution problem, abuse cases *per se* do not offer a very strong argument for regulatory changes in pesticide approvals or labeling.

Given the small number of labeled-use incidents documented yearly in Britain, there is general agreement that current labeled pesticide use does not present a problem for raptors. However, it is recognized that efforts to document causes of mortality in raptors are heavily biased toward those forms of mortality most readily detected by people (Newton et al. 1992). For British Eurasian Sparrowhawks in the 1980s and 1990s, the leading cause of mortality appeared to be collision with windows. For Common Kestrels, it was collisions with cars. Nevertheless, in the period from 1963–75, following many years of heavy use of aldrin/dieldrin seed dressings, at least 50% of Eurasian Sparrowhawk mortality and 39% of Common Kestrel mortality in southern Britain was attributable to aldrin or dieldrin intoxication (Newton et al. 1992). Although they did not analyze for intoxication by OPs and CBs in the post-OC period, they concluded that the influence of these chemicals was negligible based on the fact that the proportion of nontrauma and nonstarvation deaths declined to almost nil following the removal of OCs. This conclusion failed to consider any potential association between intoxication and trauma documented on numerous occasions in the U.S.

The magnitude and relative importance of raptor mortality from ChE-inhibiting pesticides in North America and elsewhere is more difficult to estimate. Several declining raptor populations occur on the prairies of Canada, notably Burrowing Owl, Swainson's Hawk, Northern Harrier, and Short-eared Owl (Kirk and Hyslop 1998). The association between the disappearance and reproductive failure of Burrowing Owls and the use of the insecticide carbofuran used for grasshopper control was well-documented (Fox et al. 1989). Similarly, large kills of Swainson's Hawks have been reported from the use of monocrotophos in Argentina (Woodbridge et al. 1995, Goldstein et al. 1996, Goldstein 1997, Canavelli and Zacagnini 1996). It is fortunate that the hawks are well-mixed on their wintering grounds or the impacts on some regional subpopulation(s) could have been greater (Henny et al. in press). Other factors can also explain the decline of prairie species. Burrowing Owl populations continued to decline even in years of reduced insecticide use and Swainson's Hawk breeding success is thought to have been reduced by habitat loss and food availability. The importance of OP and CB intoxication relative to other diagnosed sources of mortality was highly variable (Table 10). Very few birds were ever checked for ChE depression when an obvious cause of mortality (e.g., electrocution, trauma) was diagnosed. Routine screening of ChE levels in all raptors brought to one Virginia rehabilitation center (Porter 1993) indicated that traumatic injuries frequently accompanied exposure to a ChE-inhibiting chemical.

On a global scale, several authors who have reviewed the status of tropical raptor populations have mentioned agricultural intensification and the increased used of pesticides in intensive monocultures, such as soybean, sugarcane and rice, as potential or suspected threats (Bierregaard 1998, Virani and Watson 1998, Thiollay 1998, Mooney 1998). On a regional level, increased bird mortality resulting from exposure to ChE-inhibiting pesticides can be significant, especially in the case of rare species. Attempts to kill foxes with carbofuran-laced baits caused the loss of at least seven Eurasian Black Vultures as well as a Golden Eagle in Northern Greece (Antoniou et al. 1996). It was estimated that only 16 pairs of Eurasian Black Vultures remained in Greece (del Hoyo et al. 1994). Thomsett (1987), based on his observation of quelea control operations, believed that the use of fenthion was largely responsible for a regional decline in raptor populations in Kenya. Van Jaarsveld (1987) described the willful poisoning of at least 292 vultures over a 19-mo period in Kruger National Park, South Africa. This was of obvious concern because many species are concentrated in such protected areas. Pesticide poisoning resulting from apparently normal use of soil insecticides is a primary cause of death among Bald Eagles wintering in the Fraser River Delta of British Columbia, Canada (Table 14). In that area, the wintering Bald Eagle population increased dramatically beginning around 1978 which coincided with the first reports of pesticide poisonings (Elliott et al. 1997). The population increase was thought to reflect the continent-wide species recovery in the post-OC era (Kirk and Hyslop 1998). More wintering eagles increased the scavenging pressure and the chances that pesticide-poisoned ducks were found and consumed by eagles. Although poisoning of some local breeding birds was documented (Elliott et al. 1997), the local breeding population appeared to be stable or even increasing (Elliott et al. 1998).

Whether or not an increase in mortality resulting from pesticide use is sufficient to affect population structure or reproductive potential of affected populations, two points remain. This mortality is preventable at little or no cost to the farmer or society at large. A comparison between the U.S. and the U.K. situations indicates that a more judicious use of insecticides may greatly reduce the number of labeled-use cases, that a few products and/or formulations are responsible for most of the problems and the continuing problem with currently-registered pesticides is completely at odds with the effort and expense that groups and individuals in our society are willing to expend in order to rescue and rehabilitate individuals of those species.

REGULATORY OUTLOOK FOR PESTICIDES MOST FREQUENTLY INVOLVED IN RAPTOR KILLS

Only a few products and/or formulations are responsible for most pesticide problems.

Carbofuran. Carbofuran is the insecticide most frequently associated with labeled-use raptor mortality in North America as well as in the U.K. It was also implicated in the mortality of Bald Eagles in British Columbia, Canada before it was withdrawn from use (Mineau 1993, Elliott et al. 1996). The existing evidence points to a widespread mortality from both granular and liquid formulations in several crops (Tables 8 and 9). In the U.S. and Canada alone, kills from granular carbofuran have been documented in at least 89 species from 24 different families of birds, reflecting the scale and the breadth of the impact from this pesticide and the resulting high risk to scavenging species (Table 15). The sand-core formulation of carbofuran has now been severely restricted in the U.S. but continues to be used in rice and in a few minor crops despite a resolution of the American Ornithologists' Union asking the American government for a total ban (American Ornithologists' Union 1990) and despite similar requests from the USFWS. This formulation was canceled in Canada (Pest Management Regulatory Agency 1995) although the fate of another granular formulation, this time on a corncob base, is still hotly debated. The corncob granules, being somewhat larger than the sand core granules, contain approximately three times as much active ingredient as other granular bases of equivalent concentration. Several kills of songbirds have been reported, proving that this granule base is also attractive to birds (Mineau 1993, unpubl. data). Therefore, the risk of secondary poisoning is also present with this formulation although no cases have been reported to date. The corncob-based formulation was also available in the U.S. through local 'special-need' registrations but these may be revoked because of increasing concerns over cumulative exposure of the human population to ChE-inhibiting pesticides (the new U.S. Food Quality Protection Act). From a North American perspective, there is a continuing concern for migratory bird species from sand-core formulations of carbofuran that are widely registered in Mexico, Central and South America. They continue to be used on a very wide array of crops including rice, cotton, hemp, tobacco, peanuts, maize, coffee, bananas, oil palm, sugarcane, sorghum, citrus, potatoes, tomatoes and peppers.

The registration of the liquid formulation of carbofuran for grasshopper control and any use of the product in alfalfa were canceled in Canada (Pest

Management Regulatory Agency 1995). Unfortunately, the product continues to be used in corn and other crops despite evidence that primary kills of songbirds occur. The liquid formulation increased in popularity in the U.S. following the partial removal of the sand-core granular formulation. One of the principal uses of carbofuran in the U.S. (for control of rootworm in corn) is often unnecessary where crop rotation is practiced. Unfortunately, even growers that practice crop rotation continue to use the product prophylactically in the mistaken belief that it will increase yields (V. Sorenson pers. comm.).

Monocrotophos. This insecticide is the second most used OP in the world with the bulk of its market in the developing world (Voss and Schätzle 1994). The Swainson's Hawk incident in Argentina revived concerns over this product and raptor populations, concerns that were first expressed in Israel in the context of large-scale mortality of migrating raptors (Shlosberg 1976, Mendelssohn and Paz 1977, Mendelssohn et al. 1979). The use of monocrotophos to control voles (an abuse of the label) apparently continues in Israel (Shlosberg pers. comm.). Mass mortality of other species had also been recorded when the product was in use in the U.S. (e.g., 10 000 American Robins [*Turdus migratorius*] in Florida potato fields; Lee 1972, Stevenson 1972). The Swainson's Hawk situation has now improved through label changes and a voluntary withdrawal of the product from some agricultural areas. However, current problems with this product are not limited to grasshopper control, or to Swainson's Hawks or to abuse cases in Israel, South Africa, Argentina and elsewhere. With the assistance of two of the transnational manufacturers of monocrotophos (Novartis and American Cyanamid) a review of the worldwide database on this product is underway (Mineau et al. unpubl. data). In February 1998, Novartis Corporation announced that it was phasing out its production of monocrotophos worldwide. There are no indications that other manufacturers will follow suit. There are about 30 manufacturers of this pesticide worldwide. Together, they produce about 30 000 tons of monocrotophos annually, or enough to treat an estimated 60–120 million ha at the commonly used application rates (Novartis Corporation pers. comm.).

Fenthion Used as an Avicide. Extensive bird mortality associated with the use of fenthion for mosquito control was documented as early as the 1960s (Beard 1969 in DeWeese et al. 1983, Keith and Mulla 1966) and continued to be documented through the 1970s (Seabloom et al. 1973) and 1980s (Zinkl et al. 1981, DeWeese et al. 1983) although raptors were not reported killed in those studies. Despite documentation of nontarget bird kills from fenthion used for quelea control in 1984 (Thomsett 1987) and the Food and Agriculture Organization's (FAO) own sponsored studies in 1985 (Bruggers et al. 1989) and 1988 (Keith et al. 1994), it continues to be the principal control agent for quelea. Fenthion replaced parathion which was considered too toxic for the applicators and bystanders (Meinzingen et al. 1989). The limited market for a more selective avicide as well as the higher cost of alternatives mean that the use of fenthion is likely to continue. Fenthion continues to be registered in the U.S. for mosquito control despite the evidence of bird kills and the availability of alternatives.

Until March 1998, Rid-a-Bird™ perches continued to be used in the U.S. despite ample documentation of frequent kills of protected and endangered raptor species such as Peregrine Falcons (*Falco peregrinus*). The USFWS won several court cases and out-of-court settlements against users. In March of 1998, the manufacturer applied for a voluntary cancellation in the U.S. with a one-yr period to use existing stock. The ramifications for other jurisdictions (such as Canada) are unclear.

Famphur and Other Livestock Topical Insecticides. The problem with magpies being poisoned by topically-applied insecticides in cattle have been known since the early 1970s. The potential for secondary poisoning of raptors was demonstrated in the early–mid-1980s. Veterinary products with a systemic mode of action, such as warble insecticides, are registered under the Food, Drug and Cosmetic Act in the U.S. The FDA acknowledges the risk of raptor poisoning. Its current recommendation to users of famphur is to bury carcasses of magpies and other species killed by the product in order to prevent scavenging. The practicality of such a measure, especially with free-ranging cattle, is not discussed. The legality of disposing of protected Migratory Bird species in this fashion is also questionable. Replacing topically-applied products by a food 'pre-mix' will not resolve the problem. This leaves intubation or injection as a safer way of treating cattle. Ideally, products of lower avian toxicity should be considered for topical applications.

Table 14. Summary of North American studies investigating causes of raptor mortality. All are based on receipts of birds at veterinary and/or rehabilitation facilities.

SPECIES	LOCATION	PERIOD	NO. BIRDS RECEIVED	NATURE OF DIAGNOSTICS
Red-tailed Hawk[a]	U.S.	1975–92	163	AChE measurement when indicated by circumstances. Residues if AChE positive.
Bald Eagle[b]	U.S.	~1965–95	>4300	No screening for ChE before mid-1980s. When indicated by circumstances.
5 species[c]	Illinois	1985–87	105	
Great Horned Owl[d]	U.S.	1975–93	32	AChE measurement when indicated by circumstances. Residues if AChE positive.
Barn Owl and Pueo[e]	Hawaii	1992–94	81 B.O. 5 Pueo	AChE measurement when indicated.
13 species hawks and owls[f]	Iowa	1986–87	60	Clinical diagnosis only. Organophosphate intoxication suspected but not confirmed.
43 raptors[g]	Central Valley, California	not specified	43	Blood and brain ChE measurements. Foot residues.
Bald Eagle[h]	Fraser Delta, British Columbia	1990–95	84	Plasma and brain ChE tested in all birds where sample available. Residue determination of stomach/crop contents when pesticides suspected.
Bald Eagles[h]	Other areas of British Columbia	1990–95	217	Plasma and brain ChE tested in all birds where sample available. Residue determination of stomach/crop contents when pesticides suspected.
Bald Eagles[h]	Fraser Delta, British Columbia	1996–97	20	Plasma and brain ChE tested in all birds where sample available. Residue determination of stomach/crop contents when pesticides suspected.
Bald Eagles[h]	Other areas of British Columbia	1996–97	75	Plasma and brain ChE tested in all birds where sample available. Residue determination of stomach/crop contents when pesticides suspected.
Red-tailed Hawks[i]	Virginia	1985–90	178	Blood ChE. Exposure inferred from discontinuous (bimodal) distribution of activity levels and strong correlation between reduced levels and symptoms of intoxication, ataxia being the most common. No chemical confirmation.

Table 14. Extended.

% Positive for Exposure to ChE Inhibitors	Comments
12%	
3%	Impact trauma most frequent cause of death.
6%	
3%	Only 22 AChE tests carried out.
0%	AChE tests on 17 B.O. and 3 Pueo.
3%	
74%	Principally Red-tailed Hawks.
39–40%	Range reflects two criteria for exposure (plasma ChE reduced by 50% or 2 SD below the mean).
6.0–20%	Range reflects two criteria for exposure (plasma ChE reduced by 50% or 2 SD below the mean).
10–15%	Reduction relative to 1990–95 may reflect selective removal of more toxic alternatives.
6.7–17%	
16%	Known uses of granular carbofuran in vicinity. Higher numbers in the winter season as seen by Elliott et al. 1996, 1997.

Several ChE-inhibiting products are used on and around livestock. In the U.S., for example, they include such potentially toxic compounds as coumaphos, dichlorvos, phosmet, diazinon and tetrachlorvinfos as well as fenthion and famphur. A review of the potential for exposure and intoxication in raptors and other species is clearly warranted.

Granular Insecticides. Although secondary poisoning of raptors resulting from liquid applications of pesticides appeared to be restricted to extremely toxic products (e.g., carbofuran, parathion, monocrotophos, fenthion), granular formulations delivered the insecticide in such a high concentration that a broader selection of products resulted in toxicity to scavenging birds of prey. A good example is the series of Bald Eagle and Red-tailed Hawk poisonings in the Fraser Valley of British Columbia, Canada. Kills were initially seen with the extremely toxic carbofuran and fensulfothion (Mineau 1993, Elliott et al. 1996). Then came a number of phorate incidents (Elliott et al. 1997) when farmers switched to that granular product. When phorate was voluntarily withdrawn by the manufacturer, incidents involving terbufos and then fonofos were recorded (Tables 4, 8). This indicated that, under the particular conditions, the answer is to be found in products of much lower acute toxicity (probably nonChE-inhibiting insecticides), nongranular formulations or nonpesticidal control strategies. Whereas modifying the granule base may meet with some success in reducing kills of songbirds and other species actively seeking pesticide granules, it will not solve that particular problem which has at its root the 'passive' taking of pesticide granules from puddles and flooded field areas.

CONCLUSIONS

The loss of birds of prey to ChE-inhibiting pesticides is real and can be significant. The more we look for evidence, the more we find. Whether or not current levels of mortality from labeled uses of pesticides are high enough to affect local populations is less important than the fact that most of this mortality is easily preventable. A few regulatory actions in North America would be sufficient to solve most problems. Both in North America and Europe, more education and enforcement are needed to prevent pesticide abuse.

Recommendations for Future Research and

Table 14. Continued.

SPECIES	LOCATION	PERIOD	NO. BIRDS RECEIVED	NATURE OF DIAGNOSTICS
Bald Eagle[i]	Virginia	1985–90	14	Blood ChE. Exposure inferred from discontinuous (bimodal) distribution of activity levels and strong correlation between reduced levels and symptoms of intoxication, ataxia being the most common. No chemical confirmation.
Great Horned Owl[i]	Virginia	1985–90	21	Blood ChE. Exposure inferred from discontinuous (bimodal) distribution of activity levels and strong correlation between reduced levels and symptoms of intoxication, ataxia being the most common. No chemical confirmation.
Turkey Vulture[i]	Virginia	1985–90	21	Blood ChE. Exposure inferred from discontinuous (bimodal) distribution of activity levels and strong correlation between reduced levels and symptoms of intoxication, ataxia being the most common. No chemical confirmation.

[a] Franson et al. (1996).
[b] Franson et al. (1995).
[c] Gremillion-Smith and Woolf (1993).
[d] Franson and Little (1996).
[e] Work and Hale (1996).
[f] Fix and Barrows (1990).
[g] Hosea pers. comm.
[h] L.K. Wilson pers. comm.
[i] S L. Porter pers. comm.

Monitoring. The value of collecting and making data available on incidents is critical for the credibility of any pesticide-regulatory system. Unfortunately, very few jurisdictions are currently assembling this information, let alone providing the resources needed for adequate investigation. Also critical is the regulatory system's ability or willingness to respond to problems that are identified. A recent success has been the Argentine government's willingness to take rapid action on monocrotophos. This is in contrast to the slow pace of regulatory action on problem chemicals such as carbofuran, famphur and fenthion in North America. Also, the recent monocrotophos incidents reinforced the interconnectedness of countries and indicated that we should not become complacent about products that have been canceled or otherwise regulated or which may never have been registered in North America or Europe. Many of these products continue to be used heavily in developing countries.

The biggest problem we encountered in preparing this assessment was the lack of detail supplied with many incidents. It is critical that all available data be made available to researchers and analysts to allow meaningful conclusions to be drawn con-

Table 14. Extended. Continued.

% POSITIVE FOR EXPOSURE TO ChE INHIBITORS	COMMENTS
43%	Known uses of granular carbofuran in vicinity. Higher numbers in the winter season as seen by Elliott et al. 1996, 1997.
24%	Known uses of granular carbofuran in vicinity. Higher numbers in the winter season as seen by Elliott et al. 1996, 1997.
5%	Known uses of granular carbofuran in vicinity. Higher numbers in the winter season as seen by Elliott et al. 1996, 1997.

cerning pesticide incidents. An example of a valuable step forward is the training program on pesticide-poisoning incidents now given to enforcement agents and other investigators in the USFWS as well as efforts by the USEPA to collate this information and make it available for regulatory reviews. Making investigators aware of the relevant questions has resulted in a net improvement in the data collected and the quality of the investigations. Accounts of incidents should provide as many details as are necessary for a clear interpretation. This is especially warranted for cases that result from labeled uses or where circumstances are less clear. If incidents are thought to have resulted from abuse, or from a poor or sloppy use of the product, this should be described in detail. A good model for incident reporting can be found in ASTM (1997).

Potentially the most valuable piece of information but the one most often neglected is a thorough analysis of the gut contents in carcasses. Also, it is important for investigations to be as open as possible to new diagnoses because they can lead to surprising results. Cases involving famphur are a good example. Famphur cases were routinely thought to be abuse cases until the presence of residues on cow hair for >100 d were demonstrated, and it was documented that magpies ingested the hair. Similarly, full investigation of a disulfoton incident demonstrated that kills can result from plant-assimilated seed-treatment pesticides. Littrell (1988) investigated a number of kills from carbofuran granules in rice involving waterfowl as well as Red-tailed Hawks and a Northern Harrier. Because some of these kills occurred in autumn (outside of the usual season), he suspected abuse or serious misuse. However, the lengthy persistence of these granules was demonstrated (Elliott et al. 1996, Wilson unpubl.) showing that incidents in rice fields should now be considered in a new light.

The other major improvement needed is to increase the number of birds routinely screened for ChE inhibitors (Porter 1993, Smith et al. 1995). The proportion of birds found to be exposed (either lethally or sublethally) is dramatically higher in those situations where large numbers of birds coming into rehabilitation centers are assayed regardless of the initial diagnosis (Table 14). The link between sublethal impairment and other causes of mortality such as electrocution or impact strikes has been made often enough that this should be considered a possibility in any case investigation. ChE determinations, although not foolproof, are inexpensive and easy to perform. Automated analysis systems (e.g., Kodak Ektachem™ system) field kits with battery-operated spectrophotometers [e.g., EQM Research Inc.]) or improvements that allow the collection of blood on filter paper without need for refrigeration (Trudeau et al. 1995) puts the technique within easy reach of anyone.

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Table 15. Philogenic summary of documented cases of avian mortality in North America with the insecticide carbofuran (granular formulations) when used according to label instructions.

Order	Family or Subfamily	Common Name	No. Species Killed
Ciconiiformes	Ardeidae	waders	1
Anseriformes	Anatidae	waterfowl	12
Gruiformes	Rallidae	rails	1
Charadriiformes	Charadriidae	shorebirds	7
	Laridae	gulls	3
Falconiformes	Accipitridae	hawks and eagles	5
	Falconidae	falcons	1
Galliformes	Phasianidae	grouse	3
Columbiformes	Columbidae	doves	2
Strigiformes	Strigidae	owls	2
Passeriformes	Tyrannidae	tyrant flycatchers	2
	Alaudidae	larks	1
	Hirundinidae	swallows	1
	Corvidae	jays	3
	Muscicapidae	old world warblers and thrushes	5
	Laniidae	shrikes	1
	Mimidae	mimic thrushes	2
	Motacillidae	pipits	1
	Troglodytidae	wrens	1
	Bombycillidae	waxwings	1
	Sturnidae	starlings	1
	Emberizidae-Parulinae	new world warblers	3
	Emberizidae-Thraupinae	tanagers	1
	Emberizidae-Cardinalinae	buntings	3
	Emberizidae-Emberizinae	sparrows	13
	Emberizidae-Icterinae	blackbirds	9
	Fringillidae	finches	2
	Passeridae	weaver finches	2
Total			89

Sources: USFWS, USEPA, and CWS unpublished.

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Appendix 1. Latin names and families of avian species mentioned in the text and tables.

RAPTORS FAMILY	COMMON NAME	SCIENTIFIC NAME
Accipitridae	Cooper's Hawk	*Accipiter cooperii*
Accipitridae	Goshawk	*Accipiter gentilis*
Accipitridae	Eurasian Sparrowhawk	*Accipiter nisus*
Accipitridae	Sharp-shinned Hawk	*Accipiter striatus*
Accipitridae	Eurasian Black Vultures	*Aegypius monachus*
Accipitridae	Golden Eagle	*Aquila chrysaetos*
Accipitridae	Greater Spotted Eagle	*Aquila clanga*
Accipitridae	Imperial Eagle	*Aquila heliaca*
Accipitridae	Steppe Eagle	*Aquila nipalensis*
Accipitridae	Lesser Spotted Eagle	*Aquila pomarina*
Accipitridae	Tawny Eagle	*Aquila rapax*
Accipitridae	Wahlberg's Eagle	*Aquila wahlbergi*
Accipitridae	Eurasian Eagle Owl	*Bubo bubo*
Accipitridae	Cape Eagle Owl	*Bubo capensis*
Accipitridae	Verreaux's Eagle Owl	*Bubo lacteus*
Accipitridae	Augur Buzzard	*Buteo augur*
Accipitridae	Common Buzzard	*Buteo buteo*
Accipitridae	Red-tailed Hawk	*Buteo jamaicensis*
Accipitridae	Rough-legged Hawk	*Buteo lagopus*
Accipitridae	Red-shouldered Hawk	*Buteo lineatus*
Accipitridae	Ferruginous Hawk	*Buteo regalis*
Accipitridae	Long-legged Buzzard	*Buteo rufinus*
Accipitridae	Swainson's Hawk	*Buteo swainsoni*
Accipitridae	Swallow-tailed Kite	*Chelictinia riocourii*
Accipitridae	Western Marsh Harrier	*Circus aeruginosus*
Accipitridae	Pacific Marsh Harrier	*Circus approximans*
Accipitridae	Hen (Northern) Harrier	*Circus cyaneus*
Accipitridae	Pallid Harrier	*Circus macrourus*
Accipitridae	Black-shouldered Kite	*Elanus caeruleus*
Accipitridae	White-tailed Kite	*Elanus leucurus*
Accipitridae	White-tailed (Sea) Eagle	*Haliaeetus albicilla*
Accipitridae	Bald Eagle	*Haliaeetus leucocephalus*
Accipitridae	Booted Eagle	*Hieraaetus pennatus*
Accipitridae	Mississippi Kite	*Ictinia mississippiensis*
Accipitridae	Lizard Buzzard	*Kaupifalco monogrammicus*
Accipitridae	Pale Chanting-Goshawk	*Melierax canorus*
Accipitridae	Gabar Goshawk	*Micronisus gabar*
Accipitridae	Black Kite (European)	*Milvus migrans migrans*
Accipitridae	Yellowbilled Kite (African Black Kite)	*Milvus migrans parasitus*
Accipitridae	Red Kite	*Milvus milvus*
Accipitridae	Bateleur Eagle	*Terathopius ecaudatus*
Cathartidae	Black Vulture	*Coragyps atratus*
Cathartidae	Turkey Vulture	*Cathartes aura*
Falconidae	Merlin	*Falco columbarius*
Falconidae	Prairie Falcon	*Falco mexicanus*
Falconidae	Peregrine Falcon	*Falco peregrinus*
Falconidae	American Kestrel	*Falco sparverius*
Falconidae	Common Kestrel	*Falco tinnunculus*
Falconidae	Pygmy Falcon	*Polihierax semitorquatus*
Pandionidae	Osprey	*Pandion haliaetus*
Sagittariidae	Secretary-bird	*Sagittarius serpentarius*
Strigidae	Short-eared Owl	*Asio flammeus*

Appendix 1. Continued.

RAPTORS FAMILY	COMMON NAME	SCIENTIFIC NAME
Strigidae	Long-eared Owl	*Asio otus*
Strigidae	Burrowing Owl	*Athene cunicularia*
Strigidae	Little Owl	*Athene noctua*
Strigidae	Great Horned Owl	*Bubo virginianus*
Strigidae	Pearl-spotted Owlet	*Glaucidium perlatum*
Strigidae	Snowy Owl	*Nyctea scandiaca*
Strigidae	Eastern Screech-Owl	*Otus asio*
Strigidae	Tawny Owl	*Strix aluco*
Strigidae	Barred Owl	*Strix varia*
Tytonidae	Barn Owl	*Tyto alba*
NON-RAPTORS		
	Greylag Goose	*Anser anser*
	Pink-footed Goose	*Anser brachyrhynchus*
	Wood-pigeon	*Columba palumbus*
	Starling	*Sturnus vulgaris*
	House Sparrow	*Passer domesticus*
	Rock Dove	*Columba livia*
	Eared Dove	*Zenaida auriculata*
	Black-billed Magpie	*Pica pica*
	European Robin	*Erithacus rubecula*
	American Robin	*Turdus migratorius*
	Mourning Dove	*Zenaida macroura*
	Red-billed Quelea	*Quelea quelea*
	Barn Swallow	*Hirundo rustica*
	Dunnock	*Prunella modularis*
	Grackles	*Quiscalus* spp.